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A Framework for Invoice Management in Construction

By

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Abstract

Construction project costs are exchanged in the form of large numbers of purchase orders, which translates into many thousands of invoices. In typical contractual relationships, these invoices are exchanged between all parties involved in a construction project, including owners, engineers, architects, general contractors, sub-contractors, and many trades. The research presented in this thesis recognizes two challenges associated with invoice management: (1) the cost of invoice processing, given the involvement of numerous full-time employees from all parties involved in the project; and (2) the cost of delayed invoice payments, which is typically a cost that is consequently added to overall project cost. Ensuring on-time payment of invoices, even when funds are available, can be a challenging exercise due to the variety, the volume, and the unpredictable number of invoices received at any given time. The need for implementing processing protocols to ensure efficient management of invoices as well as procedures to minimize the amount of rework in the process cannot be ignored. This research proposes an integrated model of lean manufacturing with cohort and discrete event simulations, in order to streamline construction invoice processing and payment, ultimately minimizing invoice-processing times and delayed invoices payments. This research also proposes a cash flow management strategy and a project financial support decision model. The proposed methodology is developed, implemented, tested, and validated for two distinct sectors of the construction industry: heavy industrial (oil sands) and homebuilding.

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List of nomenclature

T_A: Time at which the invoice is received

T_B: Time within which the pay term is due

T_C: Time at which the invoice is paid

I_{lt}: Invoice lead time

I_{pt}: Invoice processing time

I_{qt}: Invoice queuing (waiting) time

I_{gt}: Invoice lag time

I_{bt}: Invoice billing time

P_t: Pay term duration

I_{pt}: Invoice processing time

I_{Ct_i}: Invoice cycle time at station *i*

V_y: Volume of invoices per year,

H_y: Number of hours spent on invoice processing in one year

P_{ij}: Percentage of hours spent by employee *j* from department *i* on invoice processing

H : Number of working hours per year

EFTE: Equivalent Full Time Employees

ER_y: Equivalent annual rate for EFTEs working on the invoice processing

T_t: Takt time

T: Time unit

λ: Number of jobs entering the system in T unit

P: Transition matrix

$S_{i,i+1}$: Ttransition probability for invoice moving from station *i* to station *i+1*

r_i : Number of invoices sent back for rework

n_i : Number of invoices moved forward to the next station

N_i : Total number of invoices received on a given day

Q: Matrix containing the eigenvectors of the matrix P^T

D: Diagonal matrix containing the eigenvalues of P^T

$P_{ref,k}$: Transition probability for reference station after *k* days

$S_{i,i+1}$: Estimates of the transition probabilities of the population $S_{i,i-1}$

$\hat{p}$: Generic symbol representing any of the proportions of interest (e.g. $\hat{s}_{i,i-1}$)

Φ^{-1} : Inverse of the standard normal distribution

b: Lower or the upper bound of the confidence interval width

F_t: Cash flow at the end of period t

f_t : Transaction amounts (cost) incurred during period t

β_{t-1}: *Impulse* function to allow the interest rate i to be applied to the cash balance $F_{t-1} + f_t$ only when the latter is negative.

if_t: Cash in-flows during period t

of_t: Cash outflows during period t

dof_t: Development cash outflows during period t

cof_t: Construction cash outflows during period t

oof_t: Overhead cash outflows during period t

$C_{l,i}^{DM}(x_{l,i})$: Cost associated with development milestone i for lot l due on date $x_{l,i}$

$C_{p,a}^{CA}(f_{p,a}^{CA})$: Cost (invoice amount) associated with construction task a for project p due on date $x_{l,i}$

$B_{p,k}^{CM}(y_{p,k}^{CM})$: Bank draw corresponding to construction milestone k for project (i.e., home) p due on date $y_{p,k}^{CM}$

$S_{p,j}^{CA}$: Starting date of construction activity j in project P

$\Delta_{p,j}^{CA}$: Duration of construction activity j of project P

$\ell_{p,s_j \to s_{j+1}}^{CA}$: Start-start lag time between sequential activities

$\ell_{p,f_j \to s_{j+1}}^{CA}$: Finish-start lag time between sequential activities

$\ell_{p,f_j \to f_{j+1}}^{CA}$: Finish-finish lag time between sequential activities

$N_{\text{day=d}}$: Number of invoices received on day d at the station of interest

$S_{p,1}^{CA}$: Start date of the first construction activity (*CA)* in project *P*

$p_{l,i}^{DM}$ ($x_{l,i}^{DM}$): Fraction (%) of the cost that needs to be paid to the land developer by day $x_{l,i}^{DM}$ after the homebuilder acquires the lot *l*.

Chapter 1 - Introduction

1.1 Motivation

The 2012 GDP of the Canadian construction industry amounted to 111 billion dollars (Statistics Canada 2011), with all commerce having been exchanged in the form of invoices. A company can receive from a few to hundreds of millions of dollars' worth of invoices every month, which makes the consequences of invoice payment delay significant and harmful. In the long term, this leads to lost profit and compromised relationships and reputations for both contractors and owners. The findings of this research demonstrate that a major owner who is equipped with the required resources, including a state-of-the-art electronic invoice payment system, delays more than 40% of invoices. Small- and medium-sized owners who have fewer resources and tools see the same results. Recently, more attention has been given to the late payment of work completed, a practice that is wrongly considered long-accepted by contractors. This has been motivating contractor associations nationwide to pursue prompt-payment legislation (Western Investor 2013). In light of these facts, it is beneficial for both the construction owner and the contractor to establish a streamlined invoice processing approach that minimizes instances of overdue invoices. The term "invoice delay" used in this research refers to a delay in payment of the contractor's invoice following receipt by the owner (or general contractor). Delays in invoice payment due to failure to comply with contractual provisions are outside the scope of this research.

A typical construction firm invoice processing system involves several full-time employees. Involved employees include (1) accounts payable to receive, verify, and pay invoices; (2) project management to approve invoices; (3) project controls to assure proper allocation of the cost breakdown structure; (4) information technology (IT) team to maintain the financial system and/or the electronic invoice tracking system (if any). For a company processing 100,000 invoices a year where an invoice takes 30 minutes to be processed, 25 full-time employees (FTEs) are needed in addition to the cost of offices, software, and equipment (computers, printers). Clearly, the effect of inefficient invoice processing on project costs cannot be ignored. It is vital for owners to implement processing protocols that will ensure efficient treatment of invoices, as well as procedures that will minimize the amount of rework in the process.

Mitigating potential financial risk helps in fulfilling the operation financial requirements of the construction company. It is not uncommon for a construction owner to delay contractors' invoices to avoid short-term liquidity deficiencies. The financial impact is significantly damaging for contractors, especially for smaller companies, who have a highly sensitive cash flow. It negatively affects developing a trustworthy and co-operative owner-contractor relationship, which in the end affects the project performance. Owners must, therefore, manage their cash flow effectively, which is possible only if cash flow predictions are correct.

1.2 Research objectives

This research is designed around the following hypothesis:

"Reducing the delay in invoice payment and managing invoice processing time will reduce the cost of the project."

The goal of this research is to:

- Develop a methodology to manage the invoice processing time
- Develop a methodology to reduce the invoice payment time (invoice lead time)
- Develop a methodology to manage corporate cash flow, thus avoiding delaying invoices as cash flow management strategy

To achieve these listed objectives, the subsequent eight steps will be followed:

- Understand the factors affecting the delay of invoice payment and the implications associated with overdue invoices
- Understand the invoice payment process and develop its value stream map using lean manufacturing tools

- Develop a simulation model to assess the efficiency and the research utilization of the resources involved in the process
- Propose an alternative process via elimination of non-adding value activities, thus reducing process time
- Assess and verify the efficiency of the future process design through the developed simulation model
- Evaluate the effect of corporate finance on the invoice process and delaying invoice payment
- Develop a cash flow mathematical model for homebuilders that is time dependent and nonlinear
- Introduce and assess cash flow management strategies for homebuilders through sensitivity analysis using evolutionary optimization.

1.3 Dissertation organization

This dissertation consists of six chapters. Chapter 1 discusses the impact of overdue invoices on project cost and its role as a cash flow strategy to mitigate financial risk. It then presents the goals and objectives of this research and the research organization. Chapter 2 evaluates the studies carried out in relevant subjects such as lean manufacturing, lean non-manufacturing, lean via discrete event simulation, lean via cohort simulation, contracts and legislation with respect to pay terms, cash inflow and outflow prediction, and cash flow management strategies. Chapter 3 provides background information on relationships between the parties involved in the construction industry, and how those relationships affect the complexity of the invoice process. In Chapter 4, the research methodologies used in each of the objective areas are outlined. This is followed by a detailed discussion of action items within the research plan. Chapter 5 presents case studies that illustrate the implementation of each of the developed methodologies and models. Chapter 6 describes the results and verification of the processes, models and methods developed through this research and summarizes the success, limitations, and contributions of the research.

Chapter 2 - Literature Review

2.1 Legal issues relevant to payment delay

Payment delay can cause significant fiscal difficulties for the creditor. As such, several jurisdictions have passed regulative measures to address payment problems. For example, in Canada, *The Public Works Creditors Payment Act* (1964) legislated a 5% interest as a penalty for late payment if not otherwise stated in the contract. The Ontario Bill Prompt Payment Act - “An Act Respecting the Protection and Viability of Construction Contractors,” (Legislative Assembly of Ontario 2011) is another example:

> *The Bill also requires payment of an amount due under a construction contract to be made within five days after a payment application is approved. A payment application is considered to be approved 10 days after it is received by the owner, an agent of the owner or the engineer or architect of record. The person responsible for paying the contractor or subcontractor who submitted the payment application may withhold payment for a portion of the contract if he or she submits a written statement describing how construction work was not carried out or related goods and services were not supplied in accordance with the contract.*

Contractor associations in British Columbia are lobbying the government for prompt payment legislation, joining contractor groups in Ontario and Alberta that are pushing for parallel regulations. This followed a discussion held by representatives of the National Trade Contractors Coalition of Canada (NTCCC) in late 2011 to inform contractor associations nationwide of the status of the Ontario Prompt Payment bill. In February 2013, NTCCC and the Ontario General Contractors Association (OGCA) agreed on a blueprint for what could ultimately become the basis for Canada's first legislation governing prompt payment (CONSTRUCTIONSLINKMEDIA 2013).

The United Kingdom passed *The Housing Grants, Construction and Regeneration Act – 1996*, in which the focus is on the contractor's right to suspend performance of his obligation under the contract if there is a delay in payment of invoices and no effective notice to withhold payment has been given (Government of the United Kingdom 1996). The *Late Payment of Commercial Debts Act* was also passed in 1998, which legislated that a payment delay interest of 8% plus the base interest rate would be applied to late payments. This measure was part of a campaign to change Britain's late payment culture, which saw eight out of ten companies habitually paying their bills late. The author of "Tackling Late Payments" (This is Money 2008), examined this culture and recommended adding a clause stating the contractor's right under the act to claim interest. The author also considered the consequences of such a legal action and their impact on the client-contractor relationship. As an alternative, the author suggested "naming and shaming" late payers through an annual ranking of British companies according to their payment performance.

Nielsen (2004) analyzed the rights of project participants under the payment provisions of the United States (US), in which the owner must pay the contractor within a specified time frame, unless the contractor's application for payment is refused by the owner's engineer. This refusal could be due to one or more of the following: (1) repeated performance failure by contractor, (2) loss or damage caused by contractor, (3) failure by the contractor to pay the subcontractor after payment from owner, (4) reasonable evidence of delay and the project will not be finished within the contract time, and/or (5) reasonable evidence that the unpaid balance of the contract is insufficient to fund the rest of the work. The decision to accept or refuse the invoice must be made within 10 days. In the event of nonpayment, the contractor may stop the work and terminate the contract. No interest rate is mentioned under these conditions in case of payment delay or the contractor resuming work after stoppage. As a remedy, most states in the US have legislated prompt payment statutes. One of Nielsen's key concerns is the conflict of some such statutes with the terms of standard-form documents. Nielsen also proposes alternatives for the avoidance of disputes to "ensure the risks attributable to payment process are fairly apportioned among the participants."

Terms change from one state to another, particularly in payment period, late payment interest penalty, whether or not the act extends to subcontractors, and the limit on the amount of retention. The payment period differs from 14 days in Iowa to 90 days in Arkansas (Gwyn 1996). The main term requires owners to pay contractors within a given number of days from the receipt of each payment. Failing to do so, the owner is liable to late payment interest penalties that vary from 9% per year in Maryland to 21% per year in North Dakota. Rourke and Gentry (2002) have sought to raise awareness among construction lawyers and professionals of the strengths and weaknesses of prompt pay acts. Several legal cases under this act were reviewed with a focus on whether or not the courts regarded payments as withheld in good faith. Reasonable causes for withheld payments are stated, which include unsatisfactory job progress, defective construction work, disputed work, third party claim, and failure to comply with any material provision in the contract; however, their interpretation is key. Scheffler (2003) believes the owner also needs protection from unfavourable provisions in the statute, particularly where the construction contract is not allowed to supersede the statute. To assist owners with prompt pay acts' provisions, Scheffler has suggested several proactive measures:

- The contract should be drafted carefully, particularly when it refers to its suppression over prompt pay provisions.
- The contract should indicate clearly the time frame in which the owner can approve or disapprove the invoice.
- The maximum withheld amount of the disapproved invoice must be revised in the owner's favour.
- The interest rate for late payment needs to be lowered.

- If the contractor resumes work suspended due to payment delay, only critical activities need to be extended.
- The contract should specify clearly the retention percentage, releasing time frame, and interest rate if payment is delayed.

New South Wales, Australia enacted the *Building and Construction Industry Security of Payment Act* in 1999. The act requires that contractors have a statutory right to receive regular progress payments from each reference date, regardless of whether the relevant construction contract employed makes such provisions (Ward et al. 2007). Under this act, a contractor can suspend work if a progress payment is not duly paid in full without notice of withholding payment. There are two other provisions in this act with the objective to reduce the adjudication period in case of payment dispute. The authors introduced protocols for clauses to be included in contracts in order to avoid unnecessary payment delay disputes.

Wu (2011) presented payment regulative measures found in Hong Kong, Australia, Wales, the United Kingdom and the United States. Wu's aim was to assist "researchers and professionals seeking to understand existing measures, and jurisdictions seeking to introduce appropriate payment protection legislation." To address payment problems in construction through regulative measures, Wu developed a gametric model based on a study of the self-seeking assumptions of human nature. Wu concluded that punishment is more effective to prevent this problem; however, it is difficult to define the will of the opportunistic party. Prompt payment acts in the UK, Australia, New Zealand, and Singapore were investigated by Maritz and Robertson (2012) with the goal of identifying legal remedies to enforce right of payment for work performed under a construction contract. The authors also aimed at improving payment practices in the South African construction industry.

2.2 *The use of lean manufacturing in invoice-like process improvement*

The nature of invoice processing is highly variable and dynamic. An ideal case is to improve a process that has one or two product types with a relatively predictable and consistent demand. Slomp et al. (2009) illustrate how lean manufacturing principles can be successfully implemented on high-variety/low-volume products. The key challenge is how to apply takt time and load-leveling principles in such a product environment. The authors defined takt time as the production pace that should be established in order to match the rate of customer demand. Simulation studies were conducted to assess the applicability of the lean production control system. The implementation of this system improved the on-time delivery performance from 55% to 80%.

Patients who are accepted in emergency departments can also be considered high-variety/low-volume products. Dickson et al. (2009) proved that the adoption and implementation of lean principles by an emergency department led to an improvement in the value of delivered emergency care. Metrics were identified and improvement was measured. The focus was on asking frontline workers across all departmental units to generate improvement ideas for process redesign. The result was a significant improvement in patient flow as well as quality of care. Patients were treated as customers as well as products whose satisfaction was one of the main success criteria.

Challenges are not limited to product variety and low volume when implementing lean techniques. Rai (2007) described other challenges such as unpredictable demand due to uncertainty over the job being awarded or not and variety in personnel skills if the process is manually driven, like the process of a document production business. A trademarked Lean Document Production (LDP) solution was invented, tested, and implemented by Xerox to improve their in-plant document production. To support implementing lean steps, the LDP solution system consisted of four software modules: data collection, performance reporting, simulation, and operations scheduling and monitoring. Applying LDP principles resulted in saving 20% of labour costs, improving productivity by 40%, reducing cycle time by 80%, and increasing revenue by 17% and annual profit by 20%. A linear programming approach was used to optimize the job schedule, so the earliest due job would be assigned to the right cell in order to maintain minimum process time.

This high potential to improve a non-manufacturing process by utilizing lean principles was subject to number of conditions. When thinking lean in any service process, basic questions must be asked: How much time and effort should be put into it? What outputs will come from it? Can the work be performed in a different way? Above all, lean cannot proceed until it has commitment from a company's top management. Tennessen and Tonkin (2007) emphasizes the fact that commitment to a never-ending improvement process by management is key to implementing lean successfully. Effective leaders know that waste is not only in shop floor activities; it can be in office workflows like invoices, engineering drawings, and estimates. An improvement in such processes requires changing the structure and dynamics of groups, which cannot be carried out without true commitment from managers.

Additional challenges such as flow complexity due to multiple departments' involvement are illustrated by Tonkin (2007b). A process map branches into multiple paths where many resources are shared. One can also see reverse flows due to poorly specified requirements. The solution is to break the process map into sub-process loops in which related areas are grouped. The author emphasizes lean training before implementation to eliminate misunderstanding throughout the lean journey. The improvement phase involves several brainstorming sessions. Hagford et al. (2007) proposed the Idea Qualification Level (IQL) system to assist in prioritizing potential project suggestions. The selected ideas are forwarded to a value engineering team to verify. The authors also highlighted improvements in an accounts payable department that utilized the IQL system. Sixty percent of invoice process activities were identified as waste and were removed. Wastes included lack of communication, lack of awareness, poor process flow, lack of training, no process owner, and unnecessary e-mails, photocopies, and logs.

In similar companies, such as one engineering firm in the UK, the focus was on office layout (2007). Changing their office layout and establishing a centralized office workflow system were the keys to achieving load leveling for the firm. One-piece flow was used so that an individual could focus on one task without being distracted by new inquiries. The new inquiries would be handled by the workflow system. Tonkin (2007a) pointed out the importance of selecting the right metrics in order to best diagnose the problem and to quantify performance gains at the end of the lean journey. The author also drew attention to selecting the right pilot process at the beginning of a lean journey.

A number of studies have examined waste in the invoicing processing. Erdmann et al. (2010) applied the criteria “define, measure, analyze, improve, control” (DMAIC) as a roadmap in the Lean Six Sigma. The goal is minimizing the invoice lead time and processing time in a consulting company to reduce its own overhead costs and assist the client to pay the consultant’s invoices sooner. The authors broke down the factors affecting the invoice process into (1) clarity of operating procedures and responsibilities, (2) adequacy of information management, (3) accuracy and timeliness of time sheets, (4) effectiveness of inspections and checks, and (5) adequacy of the computer system. Accordingly, five actions were taken by researchers and decision makers to minimize the waste: (1) standardizing the procedures, (2) centralizing the information source, (3) improving the instructions to vendors, (4) consolidating all checks to one central unit that has access to all information, and (5) improving the software system with regard to compatibility with other interfacing software, easier to fill-in time sheets, and web-based authorization instead of physical documents. Kemmer et al. (2009) applied lean principles on invoice processing. The key change was reducing batch size, thus reducing the backlog and changing the flow to pull process. The project was a pilot towards total lean administration in the collaborating company. Parson (2002) proved that shifting from manual invoice payment processing to an electronic system is not only cost effective, but also improves the relationship with vendors and reduces litigation, paper handling, and storing. In a construction company with $400 million in revenue and 150,000 invoices per year, shifting to an electronic system reduced the accounting staff by half and the invoice backlog by a third. With electronic invoice processing, invoices are received electronically by e-mail or as a hard copy by mail and scanned later on. In either case, the receiver needs to extract data from the various invoices' formats and enter it to the system as per a certain set of parameters. Data entry in the electronic invoice system is considered one of the major bottlenecks; therefore, researchers attempted streamlining the process at the data entry station by improving the interpretation of new invoices using case-based reasoning (Hamza et al. 2007).

2.3 The use of simulation in support of process improvement

Value stream mapping (VSM), a lean visualization tool, cannot respond effectively to the dynamic and uncertain nature of production processes (invoice processing, in this case). Reasons that contribute to the variability and high uncertainty of the production process have been illustrated by Wang et al. (2009), and include product uniqueness, high level of variation between products, frequent rework, and changes in demand due to urgent client needs. Such challenges underscore the value of simulation as an efficient system-modeling tool. Using simulation also allows for evaluating the efficiency of the proposed process design. Based on the adapted simulation approach to improve invoice processes, the review of past research is divided in this research into two categories: the individual-based simulation and the cohort-based simulation (Markov chain).

2.3.1 The use of discrete event simulation for process improvement

In a simulation model designed by the Wang et al. (2009), a production process for a spool fabrication shop was modeled based on discrete event simulation (DES), a sample job was loaded, and outputs were validated against historical data. Flow was improved by changing the fabrication shop layout, a change that reflects a flow fabrication system rather than an activity-oriented system. The labourers and equipment were grouped in such a way that a spool could be finished in one cell. This resulted in less traffic, no bottlenecks, and less inventory. To add more flexibility and efficiency within the model experimentation, the study enhanced the simulation model by designing and developing three new elements: assembly, batch, and unbatch. Also in the pipe production field, Božičkovié et al. (2012) presented an integration model of certain lean, simulation, and graphical tools to achieve an efficient pipe production system. Such an approach resulted in a shorter production cycle, less complex material flow, and better workspace utilization and overall organizational functionality. Tunneling was another type of construction where simulation was used as a tool for scenario-based analysis to efficiently plan the operation processes. Al-Bataineh et al. (2013) mapped the utility tunneling process, then built a simulation model to mimic this process. The authors examined numerous tunneling construction methods and scenarios to maximize productivity and, ultimately, minimize cost.

Lian and Van (2007) enhanced a simulation model to simulate the material flow, the information flow, and the general icons in the VSM. The authors introduced SimVSM as a modeling procedure that leads to: (1) generating simulation models of current and future VSMs quickly and automatically, and (2) producing thorough analysis of operational measurements such as lead-time, queuing time, and machine utilization. The model was tested on a real case from a Belgian company, in which three future-state scenarios were analyzed to assess the impact of lean-based changes on metric baselines. Abdulmalek and Rajgopal (2007) demonstrated that simulation can facilitate and validate the decision to implement lean, which in turn motivates decision makers to adapt lean to improve processes. The writers focus on the sensitivity analysis simulation models can achieve.

Through a case study in the healthcare field, Robinson et al. (2012) provided further evidence of the complementary roles of DES and lean. The authors introduced SimLean to educate, facilitate, and evaluate an approach to increase the stakeholders' involvement through the lean project lifecycle from the current state to the implementation. DES supporting lean has also been used by Garza-Reyes et al. (2012) to optimize the workload and balance an in-house production line, thus achieving continuous process flow. The simulation model helped analyze the impact of shop floor workers' rotation on the process flow, hence providing an insight to the production managers and helping them optimize the flow.

2.3.2 The use of cohort simulation (Markov chain) for process improvement

Cohort-based simulation has been widely used as a process model to determine anticipated outcomes based on a hypothetical set of inputs. The cohort simulation-based Markov chain model has been used to analyze a progression of an occurrence (e.g., a disease or deterioration in a facility) over a long-term period so an economic evaluation can be conducted. In comparison to decision trees and statistical modeling techniques, Kreke et al. (2004) suggested Markov modeling as a more suitable tool to analyze complex systems in critical care. The authors defined cohort simulation as "multiple predictions from a decision model or the determination of outcomes in a hypothetical population of patients." They also discussed the flexibility that each simulation method—Markov modeling, individual (Monte Carlo), and DES—can provide to the decision maker in evaluating different scenarios. As explained by Kreke et al., with the Markov cohort simulation the entire group of patients is represented all at once, where calculation is based on the portion of the group found in each state. The transitions can depend only on the state the portion of the cohort is in and does not take into account the impact of previous states. This is considered a limitation of the cohort-based simulation and known as “Markovian assumptions.” The authors suggested breaking down the states as much as possible to minimize the effect of this limitation. The Monte Carlo simulation, in contrast, deals with one member of the group at a time, allowing the characteristics of the individual (a patient in this case) to affect the probability of moving to a different state. DES is a mixture of the other two. An actual number of patients are represented in the model at once allowing the tracking of each individual in terms of history, recording, and interaction with other individuals. This feature in DES allows for queue development, and thus analysis of resource utilization.

Earlier, Briggs and Sculpher (1998) provided a good example in health care, in which Markov chain was used for decision-analytical modeling of disease progression over time. The objective was to validate the efficiency (cost versus quality of life) of implementing a new drug as an alternative to an existing profile of care. The aforementioned “tunnel state” approach was proposed as an alternative to modelers so they could minimize the effect of the Markovian assumption limitation. The authors further assessed the practicality and limitations of two modeling methods: the cohort simulation-based and the individual simulation-based. A similar comparison between cohort and DES techniques was conducted by Caro et al. (2003). The authors proposed using DES for an economic evaluation of health as a preferred technique. The reason provided is that modeling individuals considers the impact of the patient characteristics in computing the transition from one state to another, hence provides more accurate outputs. The authors suggested using cohort simulation when population characteristics do not affect the transition probabilities.

In construction, the Markov chain has been used as a deterioration forecast method for structures such as bridges (Puz and Radic 2011). Puz and Radic’s study proposed a regression analysis approach to develop the transition matrix based on historical data. The resulting forecast model makes possible analytical problem-solving, in which the state of the structure can be calculated at any time so that future bridge performance can be predicted. Markov chain has been also used to predict the transition of soils in order to obtain a more accurate tunneling production rate, through an approach, which assists the project manager to proactively mitigate risk and to plan on-time remedial actions (Ruwanpura and AbouRizk 2001). In this work, Markov modeling was applied to a geological problem in which: (1) the terrain was discretized into contiguous cells and (2) the author tried to quantify the probability of certain geological features in the next cell based on the state of the current cell (thereby allowing the problem to be modeled as a Markov process).

In addition, Markov chain has been used for short-term progression to calculate the cycle time of a manufacturing supply chain (Miltenburg and Sparling 1996). The authors divided improvement approaches in the cycle time management environment (CTM) into incremental (steady and not urgent) and breakthrough (urgent). Markov chain was chosen as a tool for incremental improvement, in which all activities along the process can be examined so those representing the largest components of the cycle time can be identified. Fu and Fang (2008) also developed a Markov model to calculate and manage the cycle time of the supply chain; however, the authors underlined the limitation of such a model where the time spent in one state is independent of the time spent in other states.

2.4 Finance-based decision support models for cash flow management

Viable corporate financing requires efficient cash flow management. Cash flow management involves forecasting, monitoring, and controlling payment and cash receipts (Cui et al. 2010). The task of cash flow prediction is harder in construction due to its dynamic and uncertain nature. For these reasons, the research focus has been on reliable cash flow prediction as one of the key foundations of effective cash flow management in the construction industry. In addition to traditional cost-schedule integration cash flow modeling, researchers have relied on statistical analysis of past payments to forecast future payment to contractors. Mills (2005) designed a statistical model to produce the cash flow from historical payment-contractor relationships. The research project was conducted for the North Carolina Department of Transportation (NCDOT), where 10% error was achieved for a two-year model operation. A similar statistical model was used to predict the number and frequency of the future invoices based on historical data. Simic et al. (2009) used eight years of invoice history to predict invoices and cash outflow. In their model, researchers adapted a case-based reasoning system to achieve a deviation of 1%. A multiple linear regression approach to predict the cash outflow was used by Blyth and Kaka (2006). A total number of 50 projects were used and activity breakdowns were standardized so cost and duration could be integrated accordingly. The study emphasized the uniqueness of construction projects as a key challenge to predicting cash flow and adapting the mentioned approach. The resulting predicted cash flow deviated from the estimate by less than 2.5%. A different approach based on moving weights of cost categories was used by Park and Han (2005) to forecast cash flow. Cost was categorized (e.g., material, labour, equipment) to consider different time lags as stated in contractual payment provisions. In the cash outflow model, it was assumed that the weight of each category continuously changes over the project duration to maintain the remaining budget. In the cash inflow model, the cash in is adjusted once a change in billing time occurs. Billing time is the time between the dates of bill submittal and the progress payment receipt. Tran and Carmichael (2013) considered the fluctuation of inflow the key factor contributing to cash flow prediction failure. They developed a regression-based model to predict the inflow based on an owner's historical payment behaviour.

Another essential aspect of efficient cash flow management is the cash flow planning. Researchers' attention has been on quantifying and analyzing the impact of the factors contributing to the financial cost and status, and then selecting the most effective strategies in order to reduce financial cost or mitigate financial risks. (Stolz 2010) quantified the effect of payment methods on interim financing, which is the cost necessary to finance the gap between outflow and inflow for completed scope of work. He proposed an optimal payment method as a front-end loading strategy applied on certain deliverables, such as mobilization and major equipment. In the selected tunnel construction project, the proposed front-end loading recommendations and their impact were as follow:

- Reduce retention amount by 50% at the 50% progress milestone; this reduces financing cost by 12%.
- Change the mobilization payment to better fit the actual stream of mobilization expenditure, a change that reduces financing cost by 15%.
- Revise the payment schedule of equipment procurement by front-loading equipment mobilization costs. A savings of 60% of financing cost is achieved.

The cumulative impact of the proposed recommendations is about 80% of financing cost that makes about 1.5% of the overall project cost. Touran et al. (2004) introduced a cash flow model to quantify the effect of the Prompt Pay Act on contractor profits and the cost of projects. In this act, general contractors have to pay their subcontractors' holdback upon completion of work even if they have not received their own holdback from the owner. To run the model, data was collected through a survey on transportation projects. The results of the analysis showed that the new regulations, on average, reduced the contractor's profit by 4.35%. Dayanand and Padman (2001) developed a linear, programming-based model to optimize the project payment schedule from both contractor and client perspectives. Researchers also evaluated the effect of a client-preferred payment schedule on contractor cash flow. The goal of the model is to support the client during the contract negotiation process. Easa (1992) reviewed project cost analysis models that are based on optimization to maximize the Net Present Value (NPV) of a project. These models maximize the NPV by changing unit price allocation (unbalancing models), activity schedule (fixed cash flow models), or frequency of progress payments (progress cash flow models). The author enhanced the progress cash flow model to examine the sensitivity of the contractor's profit to different progress report intervals, payment manners, and interest rates. Khosrowshahi and Kaka (2007) proposed a mathematical forecasting model that can be used as a base for financial management and decision-making. The authors introduced “preferred cash flow” after configuring the financial aspects of the project in the direction of corporate objectives. Their model enables manipulating the project parameters and provides an effective visual tool to simultaneously examine several scenarios and, in that way, achieve the preferred cash flow. Another cash flow prediction model is linear programming-based and was developed by Barbosa and Pimentel (2001) to achieve an optimal cash flow through the changing of project parameters.

Additional research has been conducted by Cui et al. (2010) using system dynamics to achieve the optimal cash balance by analyzing the impact of various cash flow management strategies. Front- and back-end loading strategies were integrated into a developed simulation model so that what-if scenarios can be analyzed to determine the most efficient strategy. By utilizing such a model, a contractor can assess the cost impact of specific contract clauses. Elazouni and Gab-Allah (2004) used integer programming to avoid exceeding the credit limit by changing activity start dates. The authors extended the project duration to provide more float to activities, then balanced the cash flow by setting minimum project extension as an objective. Fathi and Afshar (2010) used a genetic algorithm-based (GA) model to avoid reaching the credit limit. In a multi-project environment, Liu and Wang (2010) used constraint programming in another multi-project environment to achieve maximum profit by shifting activity schedules. The objective functions such as due time and credit limit were treated as constraints. Also in a multi-project environment, Abido and Elazouni (2011) developed a model in which a contractor can devise the project schedule to maintain cash availability. It is based on multi-objective evolutionary optimization where minimum project duration, minimum financing cost, minimum line of credit, and maximum profit are set as conflicting objectives. Pareto optimal curves are used to assist contractors in choosing a compromise solution. El-Abbasy (2012) added the activity mode to the decision variables list. An activity mode can be an accelerated schedule with associated overtime cost compared to the regular schedule. To achieve optimal cash flow, their developed GA model not only enables the cash flow manager to shift activity start dates but also to choose among various activity modes.

2.5 Literature review summary and analysis:

This chapter has reviewed studies aimed at reducing invoice cycle time primarily by utilizing lean manufacturing techniques. To explore other approaches and tools that can handle such a challenge (improving invoice processing), the literature review expanded and covered research carried out to improve processes in shops (manufacturing) and offices (non-manufacturing). To support their proposed approaches, researchers have used multiple tools, with the focus in this review having been on lean manufacturing and non-manufacturing concepts. Several studies have used DES or cohort simulation (Markov chain) to verify outputs and to facilitate what-if analysis. The analysis of this portion of the literature review has highlighted the potential of applying these tools in order to effectively manage invoices.

The literature review covered also the legislation in and out of Canada tending to protect contractors, particularly the risk to their cash flows due to an owner's low payment performance. The extensive attention that has been given to this zone of legislation (overdue payment) reflects the effect of the owner's payment performance on the contractor's cash flow. Such a conclusion led the researcher to direct the literature review to cash flow management and project financing. The studies conducted on cash flow management represented overdue invoices as a refuge for owners to hold capital, thus maintain cash availability for short-term funding. The studies also emphasized the importance of the accurate cash flow forecast as prerequisite to effective cash flow management. This study browsed the relevant literature review, focusing on strategies used by owners in order to maintain a favourable cash flow. The aim of such browsing is to seek alternate strategies beyond overdue invoices for owners so they can still manage their cash flow effectively.

To conclude, past studies have addressed invoice processing only from the perspective of improving the process. Within this perspective, these studies have been limited to typical non-manufacturing (or office) techniques that are derived from lean manufacturing practices. The research on cash flow management and project financing has treated the invoice delay as a “granted” cash flow management strategy that, when needed, provides more flexibility to owners in order to streamline their cash flows. Researchers have not investigated the consequences of delaying invoices on contractors, which in turn affect owners since, ultimately; both are contractors to the final product user, the public.

Chapter 3 - Background

This chapter provides background information on relationships between the parties involved in the construction industry, and how those relationships affect the complexity of the invoice process. Construction owners face two significant challenges with respect to timely payment of invoices: (1) owners must keep track of hundreds of invoices on daily bases, submitted by different contractors and subcontractors, who are working with different accounting systems, pay terms, payment schedules, incentives and other payment provisions; and (2) owners routinely face cash flow challenges during the course of the project and strategically delay invoices to manage their cash flow. However, not paying their contractors on time has other negative effects on the owner, to be explored in more detail in this chapter.

3.1 Types of contractual relationships

It is beneficial to define roles in the traditional contractual relationships. The project owner is traditionally a person or organization that pays another organization money in return for a project (Lock 2007). A contractor is the organization principally responsible for executing the project work to the customer's requirements. The project is carried out against a formal sales contract between the two parties. Figure 3-1 illustrates a typical contractual relationship where the owner outsources the work to a general contractor and a consultant, while the general contractor manages multiple subcontractors to perform the work.

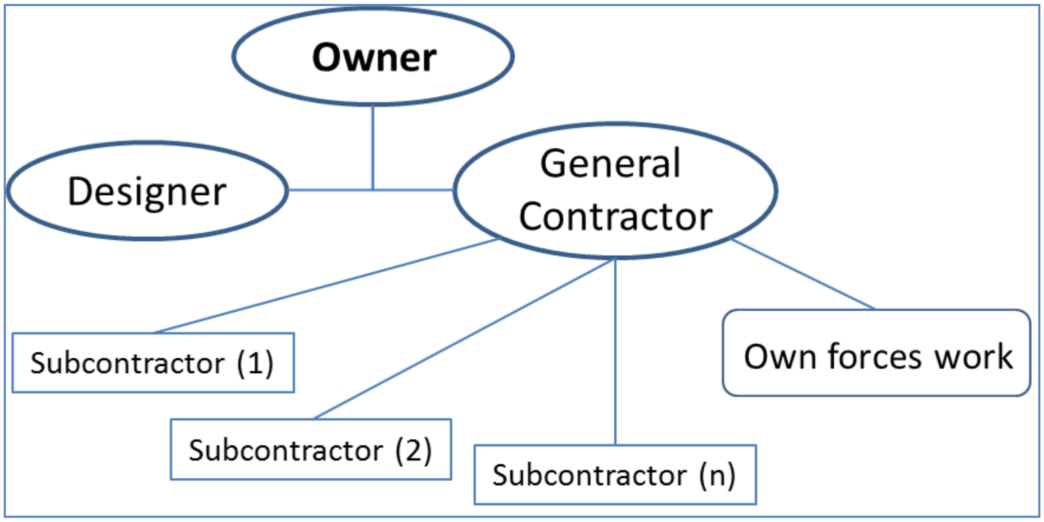

Figure 3-1. Traditional contractual relationships within a construction project

When an owner (particularly a major one) executes multiple projects, the roles shown in Figure 3-1 might be different and relationships between partners may become more complex. For example, in the heavy industrial sector (e.g., oil and gas), contractual relationships are more complicated because an owner can also operate as a general contractor, that is, some companies are owners, but also have the ability to bid on other projects for other owners. Owners of megaprojects must, therefore, micromanage projects and play owner and general contractor simultaneously, as shown in Figure 3-2. Major oil and gas companies run hundreds of projects at a time where the total installed cost (TIC) of a project can range from a million dollars (maintenance projects) to billions. Firms running projects this large will see around 100,000 invoices per year received from hundreds of contractors. Some of those contractors will overlap on different projects, but each project will have a separate contract. Therefore, one invoice from the contractor differs from another invoice by the same contractor because it is for a different project, and each project has a different cost breakdown structure. The contractor also has subcontractors that differ from project to project. The back-up (supporting) documents are different as well. Each contractor has a different invoicing system, but all of these different invoices are processed by one source: the owner.

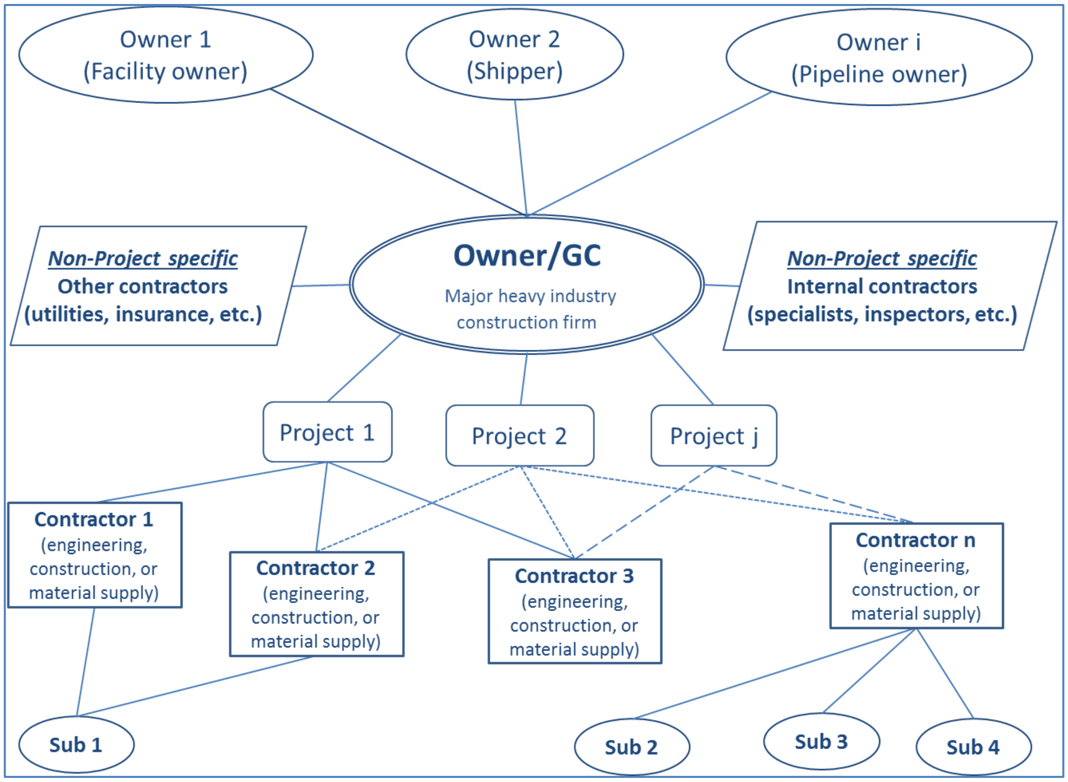

Figure 3-2. A heavy industrial firm's contractual relationships

North American homebuilders face similar invoice processing challenges. Figure 3-3 illustrates the multiple levels and contractors the homebuilder interacts with. The developer transforms farmland into an urban development by subdividing the land into lots. The homebuilder (at the centre of Figure 3-3), in turn, works for the developer. However, for each development projects, the developer spreads the lots between several homebuilders. For example, if a parcel is divided into 200 lots, there may be five or more homebuilders working for that developer. It should be noted that a developer would typically have more than one project active at any given time, as will the homebuilder. Therefore, the homebuilder may be working on multiple projects for the same or for multiple developers simultaneously, and a homebuilder may be given anywhere from one to 200 lots in a development. Large companies build between 1,000 and 1,500 homes each year, so they will have received that many lots during the past year from multiple developers. A homebuilder receives around 80 invoices for one home project. If a homebuilder is building 1,000 homes per year, that means receiving approximately 80,000 invoices per year from different contractors. This is equivalent to 320 invoices per day (assuming 250 working-days per year)

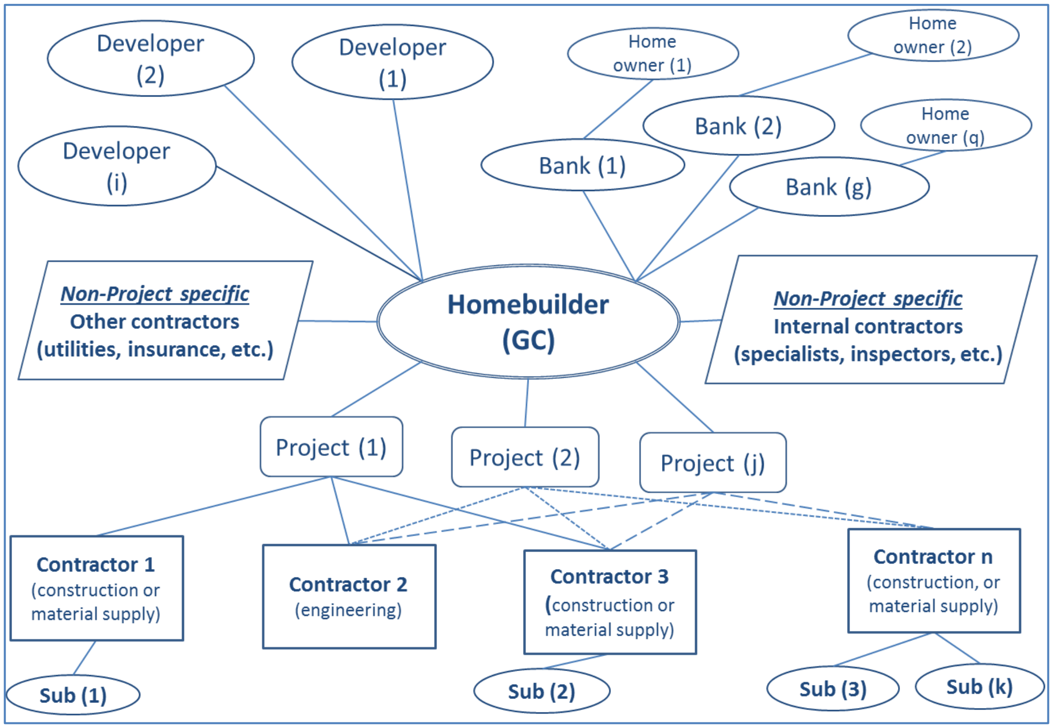

Figure 3-3. North American homebuilder contractual relationships

The challenge associated with processing invoices for payment is not only that a massive and variable volume of invoices is received each day, but also that there are various payment provisions in construction contracts. Contractors submit their invoices based on tasks performed according to a predetermined schedule, and they usually stipulate the methods of invoicing (payment provision) and payment within a targeted period, referred to as a pay term. Payment provisions can be summarized as follows:

Fixed-price Terms of Payment. These terms of payment are suitable when the scope of work is fully defined before bidding. These payment provisions are used by most homebuilding contractors. In other types of construction, such as oil and gas, the market plays an additional role in selecting this payment provision. For example, if the work is to be conducted in an area where few contractors have the capacity to take on the project, owners may accept the cost-reimbursable term of payment, although the scope of work is fully defined.

Advanced Payments. Advance payments reduce the vendor's financing charges, and are therefore considered as incentives to vendors to commence work promptly. There is a risk to owners in that they could lose the value of early payments if vendors breach contracts due to quality or progress defaults.

Milestone and Planned Progress Payments. The contractor receives payments for achieving certain milestones (defined stages of progress). This payment provision is commonly used in heavy industrial contracts. It is less common in homebuilding, except in contracts reflecting a certain scope of work, such as mechanical or electrical, where the work is split into multiple distinct phases.

Payments Based upon Agreed Rates. This term applies for oil and gas pipeline installation, cable tray installation, or concrete work for homebuilders. In this provision, payment for work performed is based on unit prices stipulated in the contract.

Contract Price Adjustment/Price Fluctuations/Variation of Price. Contracts can include terms for reimbursing vendors for escalation of their costs as per certain indices. This term is more applicable when purchasing long-lead equipment.

Cost-reimbursable Terms of Payment**.** This term is more common in heavy industrial construction and when the market is busy (i.e., less competition). There are two versions of this provision: (1) Cost plus fixed fee and (2) Cost plus percentage fee

Target-incentive Contracts. Both parties agree to share savings in cost relative to the target cost.

Convertible Terms of Payment. This term allows for changing the payment provision to unit rate or fixed price after defining significant uncertainties.

Periodic Payments. This applies to engineering companies providing services to owners. It also applies to non-project-specific contractors, such as specialists. The vendor in this type of contract is entitled to interim payments (e.g., monthly payments).

Retention. A percentage of the invoice amount is retained for a specified period by the owner. The retained amount is released once the vendor has satisfactorily completed contractual obligations (Lock 2007).

Invoice processing is a complex practice because:

- The large number of invoices received are different and unpredictable;
- Invoices can be received from consultants, material suppliers, constructors, inspectors, or internal contractors, and each has different format, backup, or cost breakdown;
- Pay terms can vary from immediate to a 30-day term, which is the most common practice;
- One owner can deal with several payment provisions at a time; and
- Other reasons, including different cost breakdown structure based on project, printed versus manually written, and different submittal methods.

Given the many different kinds of contracts and payment provisions facing both homebuilders and heavy industrial projects, keeping track of all the invoices and paying them on time while also dealing with cash flow issues presents a significant challenge. However, contractors plan their cash flow according to the agreed payment provisions and will expect their invoices to be paid within the pay term. The construction owner’s failure to meet this basic requirement will eventually impose a financial burden on the contractor.

3.2 Financial implications of cash flow management for owners and contractors

The invoice processing challenge due to the large number and volatile flow of invoices is not the sole reason for late invoice payment. In fact, owners routinely delay invoice payment as a cash flow management strategy, known as back-end loading (Blyth and Kaka 2006), to maintain the target cash balance and avoid exceeding the credit limit. Mitigating potential financial risk by not exceeding the credit limit (Elazoni and Gaballa (2004) enables the owner to negotiate better interest rates with the bank, thus setting favourable terms of repayment and reducing penalties for unused portions of the overdraft. Back-end loading is one of the key cash flow management strategies owners use to maintain that target cash balance. It is, however, effective in the short term only and strains the owner-contractor relationship. Venkataraman and Pinto (2007) defines project financing as follows:

> *”Projects are treated as distinct entities and are based on unsecured or limited resource financing. This type of financing is unsecured in the sense that the money borrowed is secured only against the project’s assets and its revenue stream. Because the investment does not show up on the company’s balance sheet, it is also referred to as off-balance sheet financing. If the project fails, the lender has no resource to recover the investment. In limited resource financing, the company has some equity in the project, which will show up on the company’s balance sheet. This type of non-resource or limited-resource financing is referred to as project finance.”*

Bank overdraft is a common financing approach in construction. It is the same as a bank loan except that interest is payable only for the borrowed amount for the period of borrowing and the account is payable on demand or upon the termination of the overdraft period. The company is allowed to overdraw up to an agreed limit (credit limit) for a prescribed period. There is also a charge on the unused part of the overdraft, but this charge is usually far less than the cost of the borrowing (10% of the borrowing cost). Other methods of funding projects include:

1. Shares such as ordinary, preference, and cumulative preference.

2. Debentures, which are loans with fixed interest rate secured by a mortgage on the firm's property.

3. Bank loans.

4. Retained earnings, which means the firm holds any profits rather than distributing them in the form of dividends.

5. Trade creditors, a financial arrangement where payments to creditors are delayed in order to ease the cash flow. The aforementioned back-end loading strategy is the reactive, short-term form of this arrangement; the proactive aspect is the arrangement of periodic payments after completion of the work.

6. Provision of corporate tax, where the tax is held to be utilized as short-term funds until it is paid at the fiscal year-end.

7. Depreciation, which is an internal source of capital that can be available when no more depreciation is charged (Venkataraman and Pinto 2007).

As advanced by Venkataraman and Pinto, cash flow—how money moves in and out of a business—and cash flow management—the timing of moving the money—are vital aspects of project management. Project managers know that if a project runs out of funds, even if it is progressing technically and meeting timelines, it will be considered a financial failure.

Hendrickson (1989) explained the difference between project and corporate financing, illustrating the short- and long-term plans to finance a project. Hendrickson also evaluated several project financing plans in terms of profitability to the owner based on net present value. The author discussed payment delay as an owner strategy to overcome liquidity shortfalls; however, this approach has a long-term impact since contractors tend to allow in their bids for the resulting financial burdens.

Even with the availability of numerous sources of capital, maintaining a financially healthy company is difficult. Financial risks like delayed owner payments, changes in interest rates, changes in operations plans and schedules, and changes in cost (Barbosa and Pimentel 2001) all take their toll. The level of risk is even higher in the homebuilding business due to specific factors such as (1) the diversity of the product type (lot, pre-sale home, show home, and speculation home); (2) continuously changing market conditions; and (3) the variety of contractual agreements with the involved stakeholders like banks, land developers, and homeowners. Short-term problems (up to two weeks) can happen when bank draws are delayed during times when vendor and developer bills and internal payroll are due. In the longer term, homebuilders may find themselves facing a liquidity squeeze from unanticipated market changes and/or a deficiency in their cash flow prediction system.

Financial managers respond to cash flow problems by time horizon, namely short- or long-term. Accordingly, the development of a proactive and sustainable cash flow management system to mitigate financial risks, for short and long terms, cannot be ignored.

Predicting cash flow for homebuilders does present its own challenges, including:

1) The high product volume (homes) and short construction duration;

2) The variety of products that includes lots, pre-sale homes, and speculation homes; and

3) Unanticipated market behaviour, mainly regarding the sale of speculation homes.

These factors further expose homebuilding corporations to financial risk. For any company, failing to predict cash flow accurately leads to ill-advised financial decisions and the potential for bankruptcy (Kaka and Price 1994). Consequently, to fulfill the financial requirements and avoid the inherent financial risks, the construction industry requires efficient cash flow management that is based on an accurate cash flow prediction model and efficient use of available cash flow strategies.

3.3 Impact of delayed invoice processing on owners and contractors

Ensuring on-time payment of invoices, even when funds are available, can be challenging. Payment plan. Although the appropriate payment method and payment protection regulations are (or will be) in place, owners still delay contractor invoices. Meanwhile, contractors prefer not taking legal action in the case of delayed payment as it may jeopardize their relationships with owners (Wu et al. 2011). Subject experts emphasized that payment security acts are still not sufficient to solve the cash flow problem faced by contractors (Oxlade 2004). Options available to contractors include, but are not limited to:

- Adding a cost allowance element to the project bid price to accommodate the effect of such risk;
- Offering incentives to owners if invoices are paid within the pay term; and/or
- Allocating resources to track overdue invoices being held by construction owners.

Delayed invoices impact owners in terms of cost and reputation as well. For instance, the relevant costs to the contractor are transferred back to the owner as project costs. In addition, continuous delaying of invoice payments by a particular owner could have a negative effect on their reputation in the eyes of contractors.

The financial effect of negative image is difficult to quantify, but some contractors do consider overdue invoices a criterion in deciding whether or not to bid. As Hendrickson (1989) has asserted:

> *"Since contractors do not have large capital assets, they typically do not have large amounts of credit available to cover payment delays. Contractors are also perceived as credit risks in many cases, so loans often require a premium interest charge. Contractors faced with large financing problems are likely to add premiums to bids or not bid at all on particular work."*

Another example of the impact of the overdue invoices on owners' reputations is that contractors in the UK suggested publishing a "shame list" of owners with low on-time payment performance (This is MONEY 2008). These impacts make it paramount for both the construction owner and the contractor to establish a streamlined invoice processing approach that minimizes processing time and instances of overdue invoices.

Chapter 4 - Proposed Methodology for Invoice Management

This research proposes a framework for the owners to minimize the overdue invoices following a dual-perspective approach. First, it provides alternatives to the traditional methods aimed at streamlining the invoice process, thus reducing the invoice lead-time. Second, it explores alternatives to manage the owner's cash flow so there is no (or minimum) need to delay invoices as a cash flow management tool. Figure 4-1 presents the framework proposed in this research. To promote the application of a lean invoice system, lean application strategies were developed, including constructing a lean invoice model and facilitating lean improvement efforts. To understand the specific homebuilders' project acquisition with elements contributing to the cash flow prediction, the author conducted meetings and interviews with expert staff of the studied companies. The case-based research method adopted in this thesis reflects the nature of the research work. As per Figure 4-1, the research proposes two methods to handle the process of invoices; both are based on a thorough analysis and assessment of the invoice system according to specified criteria. The integration of lean manufacturing and DES is the first method, while the second is the Markov modeling or cohort-based simulation model. In order to measure the degree of the problem and to analyze the system behaviour towards certain criteria, a preliminary assessment of the existing invoice processing system is conducted. The process owner at this point can choose which method to adopt—discrete event or cohort-based simulation based on trade off analysis between effort and precision. A further and more in-depth assessment of the invoice processing system then follows. This detailed process assessment level requires an extensive search for information and data within the company.

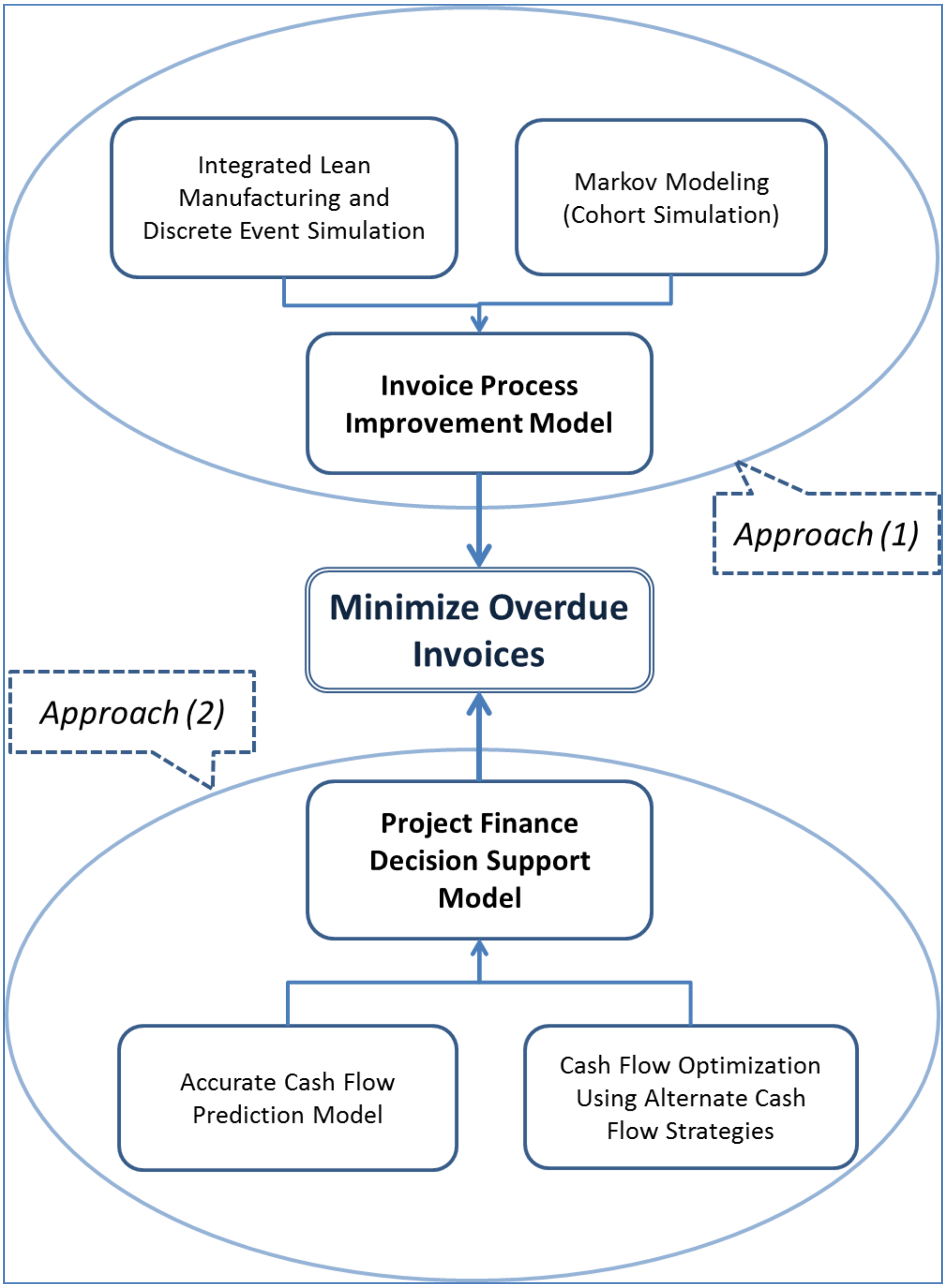

Figure 4-1. Dual perspective approach towards minimizing overdue invoices

Since invoices are sometimes delayed on purpose so owners can maintain their short-term cash flow, this research proposes using alternative cash flow strategies also available to owners instead of delaying invoices. Approach 2 in Figure 4-1 presents this standpoint of the model and proposes developing a finance decision support model that follows two steps: (1) developing a cash flow prediction model, and (2) using this model as an optimization tool to streamline the predicted cash flow and mitigate financial risks.

4.1 The invoice processing approach

The analysis begins with an overview of the basic definitions and terminology encountered with respect to invoicing and invoice processing. Parties are bound contractually to a specific pay term ($\mathbf{P_t}$) that specifies the time needed to pay an invoice, which is calculated satisfying Equation (1). The length of time the invoice is circulated (processed) in the organization is referred to in this research as invoice lead time ($\mathbf{I_{lt}}$), which is calculated satisfying Equation (2). An invoice is considered overdue if it is paid after the pay term due date (Figure 4-2); the invoice overdue time ($\mathbf{I_{ot}}$) is thus calculated as per Equation (3).

$$P_t = T_B - T_A \qquad (1)$$

$$I_{lt} = T_C - T_A \qquad (2)$$

$$I_{ot} = T_C - T_B \qquad (3)$$

Where:

T_A is the time at which the invoice is received,

T_B is the time by which the pay term is due, and

T_C is the time at which the invoice is paid.

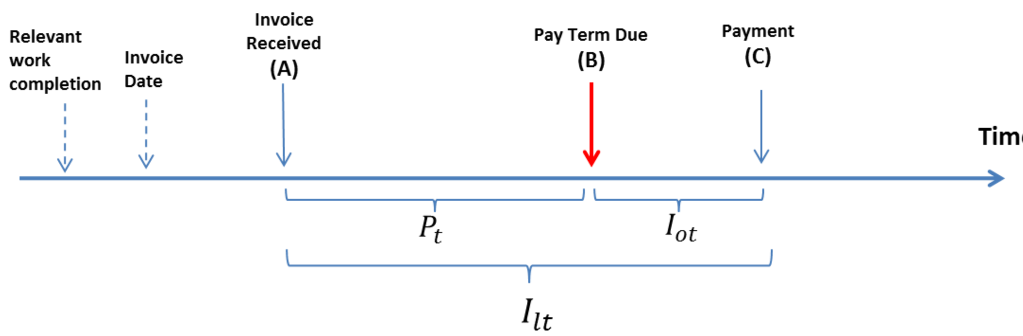

Figure 4-2. Invoice lead time (I_{lt})

The invoice processing time ($\mathbf{I_{pt}}$) can be calculated as per Equation (4), which combines cycle times for all stations along the invoice processing production, from receipt of invoice to payment (Figure 4-3(a)). The cycle time ($\mathbf{I_{Ct_i}}$) is the time, usually in minutes, to process an invoice through one station($\mathbf{i}$) . Stations can include receiving, photocopying, checking, and reviewing, with payment or issuing a check at the last station. The invoice processing time can also be defined as the difference between the invoice lead-time and the invoice waiting (queue) time ($\mathbf{I_{qt}}$) (Figure 4-3(b)).

$$I_{pt} = \sum_{i=1}^{n} I_{Ct_i} \tag{4}$$

Where n is the number of stations along the invoice process.

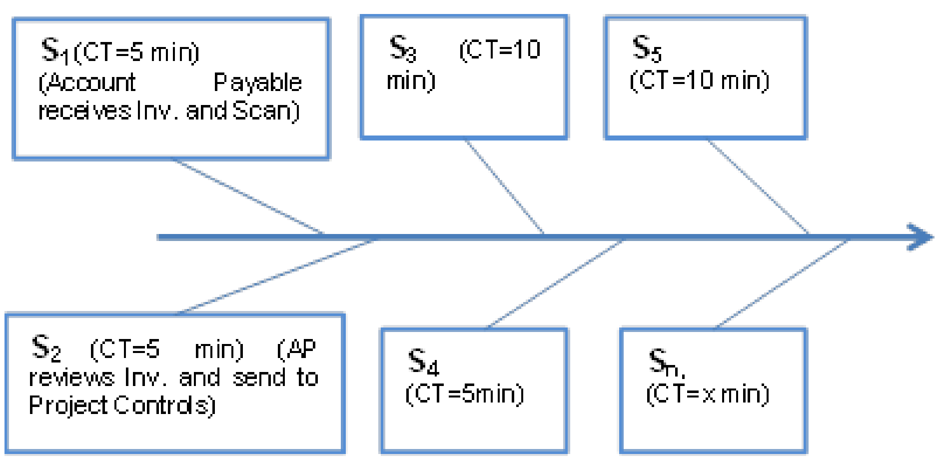

Figure 4-3(a). Invoice processing time as combination of tasks' cycle times

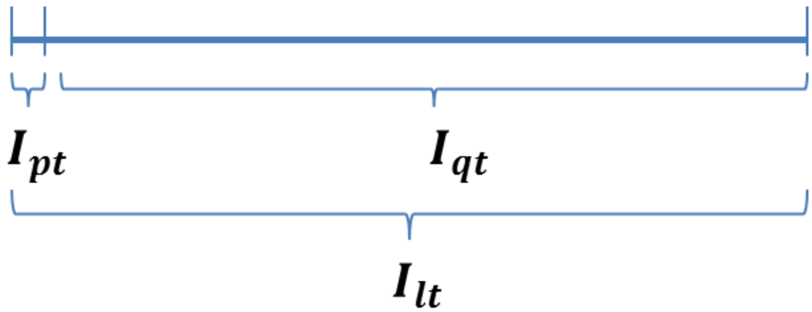

Figure 4-3(b). Invoice processing time as small portion of invoice lead time

In this research two approaches are introduced to improve invoice processing on the owner side from the time the invoice is received to the time it is paid. The first approach uses integrated lean manufacturing and DES; the second approach uses cohort simulation (Markov chain) modeling.

The data is collected through two phases, initial and final (or detailed). The purpose of initial data collection is to:

1. Calculate the actual values of the two chosen system metrics: the invoice processing time (I_{pt}) and the invoice lead-time (I_{lt}).

2. Assess the problem's magnitude with respect to the two metrics. From the lead time perspective, the assessment is carried out by (1) calculating the ratio of overdue invoices and (2) analyzing the distribution of invoices due to their lead times, while from the processing time perspective, the assessment is done by computing the invoice processing cost as a ratio of total overhead cost and comparing it to a benchmarking ratio.

3. Conduct sensitivity analysis to understand the behaviour of the invoice processing system towards certain criteria, thus identifying general system characteristics. These characteristics include, but are not limited to, the response of the system to invoice daily flow (demand), pay terms,

contractor, contract type (lump sum, cost plus, etc.), and/or discipline (engineering, construction, or supply).

The initial data collection method depends on the invoice processing system (manual or electronic) in place and the information available in each of them. On the one hand, the electronic system can be an advanced one, in which the two aforementioned parameters can be extracted automatically followed by minimum data organization to fit the purpose of the analysis. On the other, a manual system may necessitate separating a representative sample of invoices in every month and extracting the required data from each invoice to enter into pre-set forms or templates. Table 4-1 explains the type of information collected and the associated purpose.

Table 4-1: Data collection method for preliminary invoice process assessment based on invoice lead time

Data collected (or calculated)	**Purpose of data collection**
Invoice receiving date	To calculate invoice lead time and to evaluate impact of ot time and seasonality on overdue invoices
Invoice payment date	To calculate invoice lead time and to evaluate impact of ot time and seasonality on overdue invoices
Pay term	To calculate invoice overdue time and to evaluate impact of pay terms on overdue invoices
Invoice #, contractor name, contract type, service provided, invoice amount	To assess impact of different contractors, type contracts, and service on overdue invoices

The data collected for processing time can be generated from a questionnaire distributed to staff involved in the process. This includes staff in accounting, project management, project controls, and inspection. Figure 4-4 explains the data collection method for the preliminary assessment of the invoice processing system regarding invoice-processing time (I_{pt}).

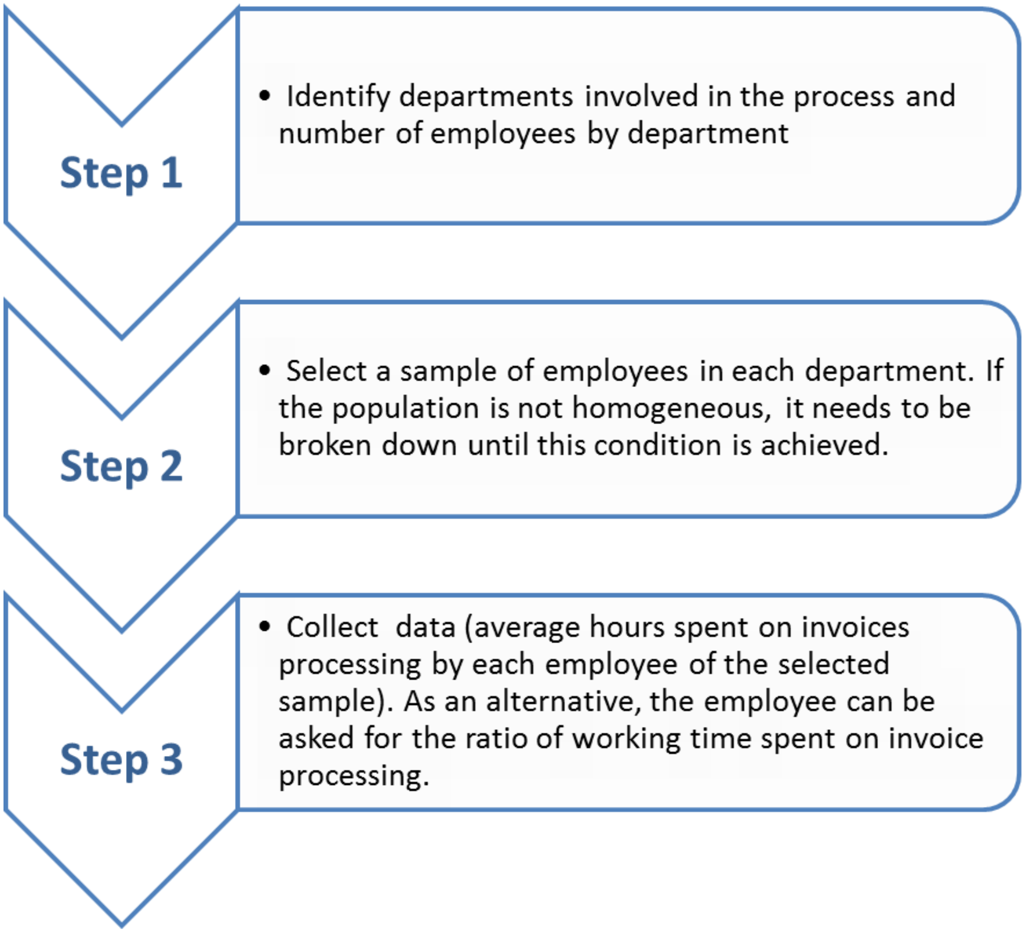

Figure 4-4. Data collection method for preliminary invoice process assessment based on Invoice Processing time

The average invoice processing time per invoice can be calculated satisfying Equation (5):

$$I_{pt} = \frac{H_y}{V_y} \tag{5}$$

Where:

$$H_y = \sum_{i=1}^{n} \sum_{j=1}^{m} P_{ij} H \tag{6}$$

In which: V_y is volume of invoices per year, H_y is the number of hours spent on invoice processing in one year, P_{ij} is percentage of hours spent by employee *j* from department *i* on invoice processing. H is the number of working hours per year, *n* is the number of employees in department *j*, and *m* is the number of departments involved in invoice processing. The Equivalent Full Time Employees (EFTE) spent on invoice processing can be calculated satisfying Equation (7), from which the cost of processing invoices by year (C_y) can be generated as per Equation (8).

$$\text{EFTE} = \frac{H_y}{H} \tag{7}$$

$$C_y = \text{EFTE} * ER_y \tag{8}$$

In which ER_y is the equivalent annual rate for EFTEs working on the invoice processing.

Once the preliminary assessment of the invoice processing system that is based on the initial data collection is complete, a final data collection (phase 2) must be conducted. However, the technique implemented in phase 2 depends on the method selected to improve the invoice process. Therefore, an introduction and a proposed methodology for each of process improvement methods is presented, which includes the description of phase 2 of data collection.

4.1.1 The integrated lean manufacturing and discrete event simulation for invoice processing

Lean manufacturing philosophy, a process of eliminating waste with a goal of creating value, will be applied to segregate the value adding from non-value-adding activities in the invoice process. Invoice processing is considered in this research similar to the manufacturing process (assembly line) due to the following parallels:

- The invoice is viewed as a manufacturing product that moves from one station to another along the process line until it is delivered (paid). It has its own lead-time and processing time.

- At each station, employees add value to the product (invoice) in the form of checking, approving, and paying. In case a defect is noticed, a rework is generated.

- Invoices can be of different types (material supply, installation, internal contractor), and each has its own components. These components are checked (instead of being "installed") along the assembly line

The similarity between invoice and manufacturing processing makes lean manufacturing techniques applicable to invoice processing. VSM as a lean manufacturing tool is utilized in this research. The advantages of VSM are summarized by Rother and Shook (2003) as follows:

- It provides an effective tool for clear communication by visualizing the actual material and information flow.

- It exposes wastes through mapping and lean measurements.

- It becomes the blueprint of lean transformation by integrating lean principles and techniques into the future map. Management review and reporting are incorporated.

- It is a qualitative tool but describes the quantitative details of the flow.

The main system process is illustrated in Figure 4-5. The aim of applying lean manufacturing to invoice processing is to achieve a lean invoice process that leads to minimum invoice lead time and processing time; to establish a quality control system that monitors process behaviour regarding waste, queue time, and other lean parameters; and to create a float in invoice lead time to be utilized as a cash flow management strategy. The application of lean begins with developing a Current State VSM (C.S.VSM), which is improved upon in order to reach the

Future State VSM (F.S.VSM). Simulation is used to validate the improvement strategies, and a sensitivity analysis is conducted. These steps need to satisfy certain criteria, such as the company's organizational structure, the technology in use, the product (invoice) type, and the pay terms applied. The required inputs are the lean parameters, such as queue size and location, along with rework volume by station

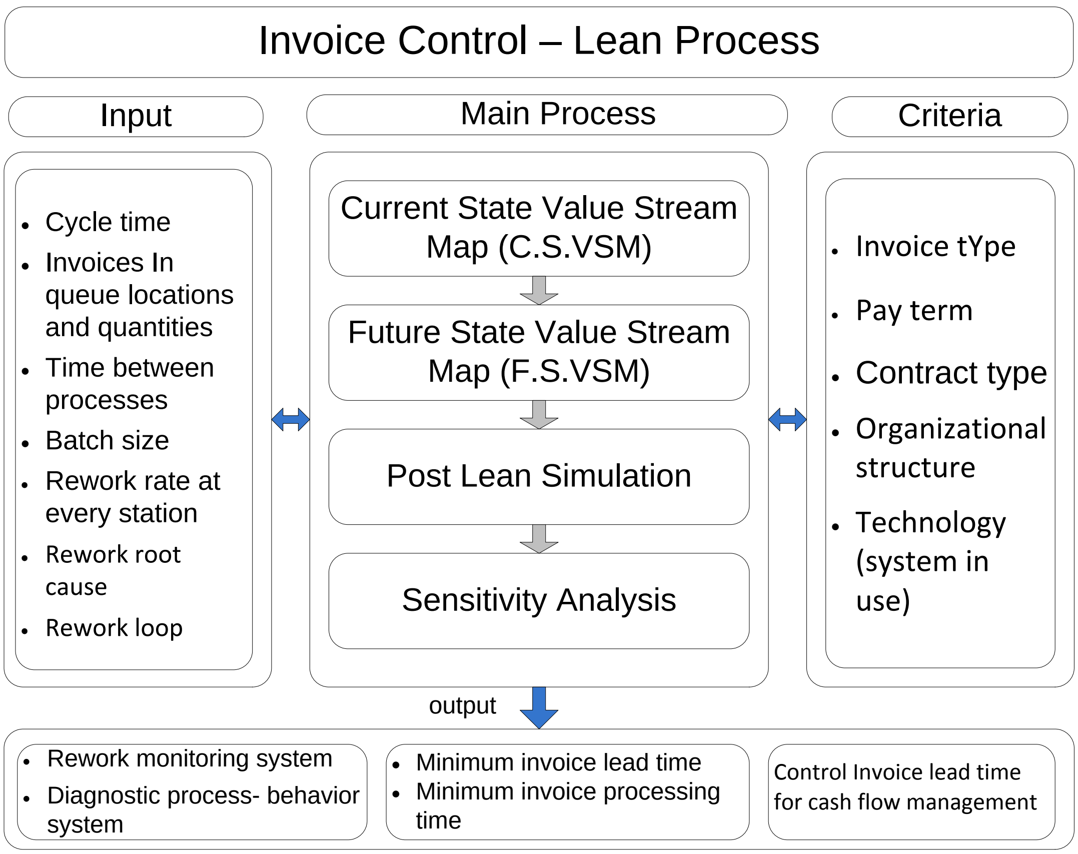

Figure 4-5. Lean invoice: Main system process (phase 1)

A lean project consists of the following stages:

1) Form the team (lean steering committee): This includes process experts, personnel involved in the process, and decision makers. Seminars can be held to present the value of lean manufacturing and gain the buy-in from company decision makers. This was not necessary for the collaboration company due to their good experience applying lean

principles on their shop floor. However, short education sessions were required for staff involved in invoice processing. The main tasks of the team are to help develop the process chart as a base of the C.S.VSM, identify waste in the process, discuss improvement ideas, and evaluate their visibility and practicality prior to implementation.

2) Build invoice C.S.VSM: The process mapping starts from developing the process flow chart to document the process flow, thereby facilitating communication between stakeholders and focusing on areas of improvement. This turns to the C.S.VSM after collecting real time data for each station along the process of the (1) cycle time, (2) lead time, (3) and rework rate. The method of phase 2 data collection depends on the existing invoice processing system: manual or electronic. If manual, a template can be developed to record the lead time of every invoice in a selected sample at each of the stations along the invoice processing system. These invoices are pushed into the system where the start date and time of every task along the invoice journey is collected (Figure 4-6). The lead-time of a task (i) can be calculated by subtracting its start time from the task (i+1) start time. To simplify, the processing time of task (i), which is (in minutes) compared to its lead-time (mostly in days), can be ignored. For task (i) cycle time, a stopwatch can be used to collect the time (preferred for a batch of invoices) before and after the task is complete. Then the cycle time is divided by the number of invoices in the batch. This effort and time to collect data in the manual invoice system can be significantly reduced if the invoice system is automatic.

   Since construction seasons have a substantial impact on invoice variation (i.e., busy in summer and slow in winter), invoices need to be selected to reflect this type of pattern. Another pattern that needs to be considered is the variation in invoice volume between the middle and end of the month, especially if the owner pays on semi-monthly cash run basis. Vacation period (July and August) also needs to be taken into consideration: when combined with the busy construction season, the vacation period has a significant impact on invoice lead time. The human factor has to be taken into account as well, since every employee has different skills and productivity. For the electronic system, the required data to calculate invoice-processing time, lead time, and rework rate at each task can be retrieved in a very short time with respect to the aforementioned invoice variation factors.

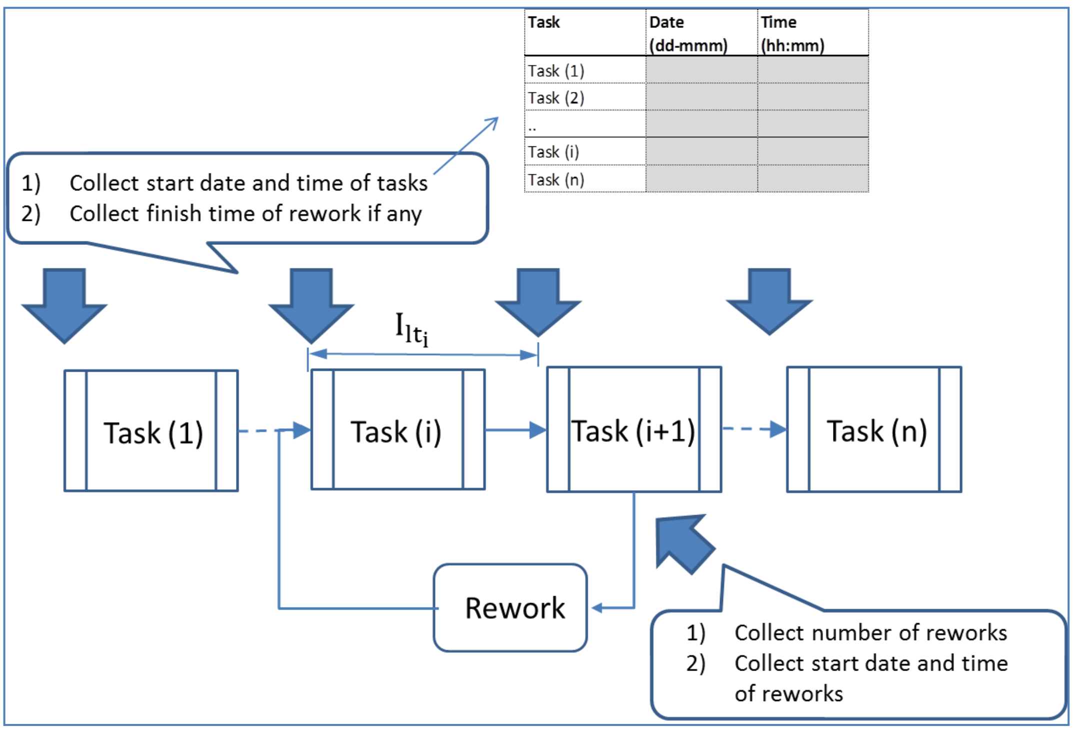

Figure 4-6. Data collection (phase 2) to calculate lead times for tasks including reworks and to collect rework data in a manual existing system

3) Identify metrics/baseline: Metrics selection drives the behaviour of the lean project. The metrics' values establish the baseline of the lean project, to which the results will be compared so the performance of the lean project can be measured when the future state is reached. The selected metrics are the invoice processing time (I_{pt}) and the invoice lead time (I_{lt}).

4) Develop the simulation model: The C.S.VSM is modeled using Simphony.NET, a DES tool developed at the University of Alberta. The simulation model complements VSM by representing the dynamic nature and uncertainty of invoice processing, with the attributes of each task expressed in the form of a distribution. It also analyzes what-if scenarios of the flow design improvement in order to validate prior to implementation.

5) Build the future state value stream map F.S.VSM: Lean parameters and scope of every step in the existing process is assessed to identify wastes and their root causes. The focus of future state mapping is to eliminate waste due to rework, which is the main reason for excessive processing time, and to maintain a continuous flow of invoices throughout the process line to reduce the invoice queue time, hence the invoice lead time.

   (a) Reducing waste due to rework: The invoice consists of several components, such as the invoice summary page, the invoice cost breakdown page, the contract (or purchase order (PO)) copy, and so on. Each of these includes certain information that needs to be dealt with according to the station along the invoice process. The main task in the invoice payment process is assuring these components are in compliance with the contract. Any deficiency triggers a rework or waste depending on its type and checking location within the process. Data are collected for each rework type regarding its frequency, causes, and resulting loss of time. Depending on the rework root causes, the correction measures can be through standardizing procedures and instructions to vendors by establishing and enforcing vendor invoice requirements in order to:

      - Reduce payment errors and reduce effort required to manage incomplete invoices, and
      - Move checking point upstream so reworks, if they happen, will have a shorter loop until they are corrected.

(b) Creating continuous flow: There are two main challenges to continuous flow: (1) the variation of invoice production (daily received invoices), and (2) the unlevelled loading on stations along the process. Lean manufacturing tools, such as load-leveling and takt time (the demand-based mean interarrival time, i.e., the average time between two invoices), respond to these challenges:

- The takt time (T_t) can be calculated satisfying Equation (9).

$$T_t = \frac{T}{\lambda} \tag{9}$$

Where:

T: is the time unit

λ: is the number of jobs entering the system in T unit

- The pacemaker station: The task of the pacemaker is to feed the system with invoices as per the takt time. For example, the pacemaker can be the first station in the process. Regardless of what is received from contractors, the receptionist (first in the process) releases a batch of invoices as per batch takt time.

- Load levelling: The queue time and number of invoices at every station explain the bottlenecks. A key lean principal is to make the mean takt time equal to the mean service time, which is the required time to complete the job. For example, if the service time (lead time) to process a 100-invoice batch in the payment phase is 400 minutes, and the takt time for the batch is 120 minutes, then four account payable employees (400/120) would be needed to process arriving invoices with no queue accumulated at arrival point.

6) Apply post-lean simulation: To validate the process improvement and to facilitate the implementation, the simulation model has been run for the F.S.VSM. The process improvement has been measured by comparing the new metrics' values to the original ones.

7) Implement and verify: As the invoice payment has no allowance for trial and error, an experimental framework is necessary to allow gaining confidence in the efficiency of the new alternative prior to its real-life implementation.

4.1.2 Modeling invoice process using Markov chain (cohort simulation)

As an alternative to the lean-DES integrated method, the Markov chain model is able to evaluate the current invoice process, thus identifying the existing bottlenecks and assessing their severity in order to prioritize the improvement steps. Developing this model starts from creating a process chart that reflects the current state, then collecting the data necessary to develop the transition matrix, by which bottlenecks can be identified (Figure 4-7). Sensitivity analysis can be carried out examining improvement scenarios proposed by the process owner.

According to Markov process theory, a system with m possible states in which changes occur at discretized values of the parameter, which is discretized on a daily basis), the probability that the system will be in state $X_{n+1} = x_{n+1}$ on day D_{n+1} is defined with respect to all previous states as $P(X_{n+1} = x_{n+1} \mid X_0 = x_0, X_1 = x_1, \cdots, X_n = x_n)$. Of course, in order to be considered a Markov process, the state X_{n+1} should be conditioned by the previous state only, thus leading to the definition, $P(X_{n+1} = x_{n+1} \mid X_0 = x_0, X_1 = x_1, \cdots, X_n = x_n) = P(X_{n+1} = i \mid X_n = x_n)$ (Fu,Qiu-Fang 2008)

In the case of invoice processing, the number of invoices at station n + 1 is conditioned by the number of invoices at the previous station. Because of this parallel, Markov modeling applies.

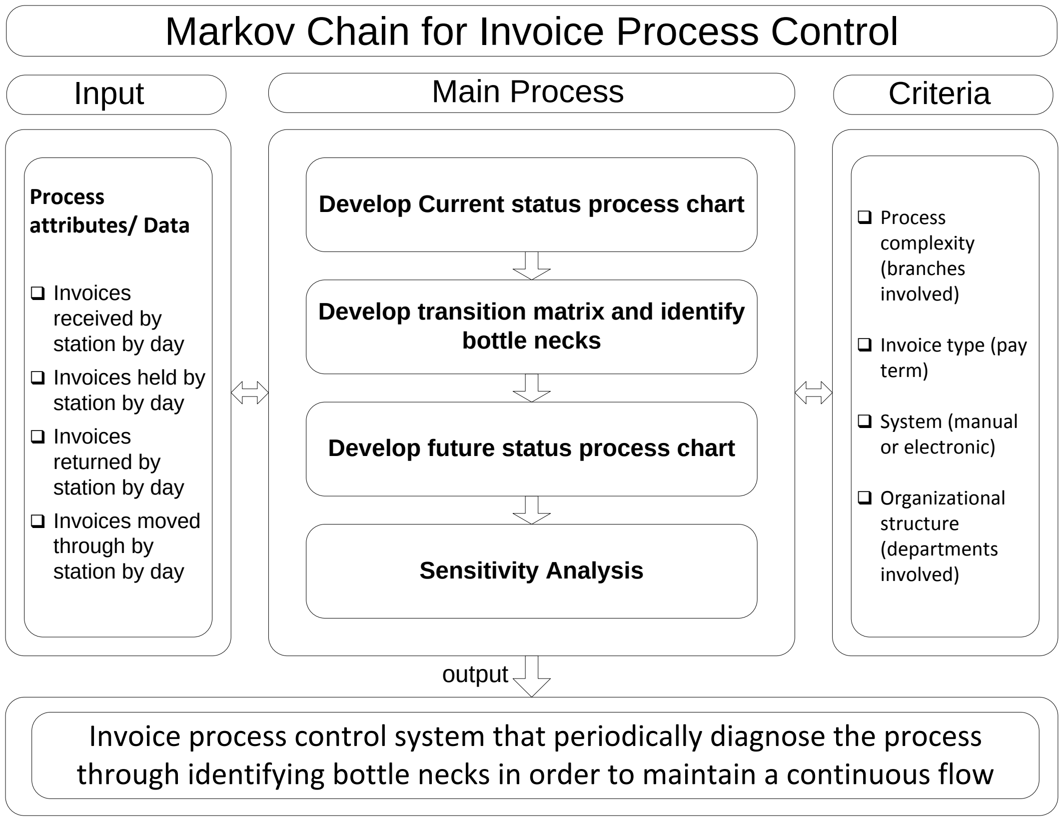

Figure 4-7. Markov chain model: Main system process

This model requires taking into account several constraints, namely (1) the complexity of the process, particularly if there are branches involved; (2) the invoice type (pay term) and if the system prioritizes accordingly; (3) the system type (manual or electronic), which affects the data collection and improvement strategy; and (4) the departments involved as this limits the flexibility of collecting data as well as implementing improvement.

Processing an invoice, (or, more generally, a document), in a supply chain-like environment consists of pushing the document from one station to the next until it reaches the end of the chain, at which point the document is considered to be complete, that is, processed. However, since at each station there is a possibility of rework because of inconsistent or incomplete information, the document can sometimes be pushed back to a previous station, hence leading to the flow map depicted in Figure 4-8.

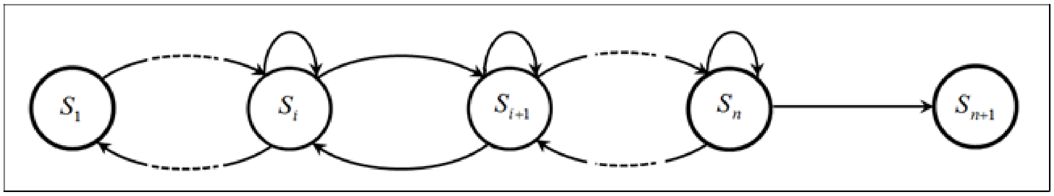

Figure 4-8. Flow diagram for a document being processed in a supply chain-like environment

According to Figure 4-8, rework of a document may occur at the station at which it is currently being processed (usually because of missing information which needs to be provided by the “contractor”), or pushed back to a previous station if the employee detects inconsistent data. Although rework can push back a document at any number of stations, in practice, chain-like document processing is usually set up so that each station acts as a quality control of the previous one. As a result, when a document moves along the stations, an agent at a given station will update the document only if the data from the previous station are consistent with the update that is about to occur. The flow model described in Figure 4-8 can be represented by a Markov model whose transition matrix (*P*) satisfies Equation (10).

$$P = \begin{pmatrix} s_{11} & s_{12} & 0 & 0 & \cdots & 0 & 0 & 0 \\ s_{21} & s_{22} & s_{23} & 0 & \cdots & 0 & 0 & 0 \\ 0 & s_{32} & s_{33} & s_{34} & \cdots & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & \cdots & s_{n,n-1} & s_{n,n} & s_{n,n+1} \\ 0 & 0 & 0 & 0 & \cdots & 0 & 0 & 1 \end{pmatrix} \quad (10)$$

The elements of P are the probabilities of a document to move from its current station (i) to one of its immediate neighbours ($i-1$ or $i+1$) or to remain at its current location. Note that because of the constraint imposed on the document processing protocol, the transition matrix is tri-diagonal. The last station in this matrix, indexed as $(n+1)$ is, in fact, a virtual or absorbing state, since, once a document is considered complete, it remains indefinitely in such a state. Two major outcomes at this juncture are of interest to the invoicing manager or department: (1) the number of cycles (expressed in days) required to process a given document, and (2) (perhaps) stochastic sensitivity analysis. In practice, the daily volume of documents leaving each station must be observed (phase 2 data collection) in order to determine the transition probabilities, as must the number of invoices pushed back (because of rework) and the number of non-processed documents which remain at the station (backlog) to be treated during the next cycle. The transition probabilities ($s_{i,i-1}$) and ($s_{i,i+1}$) can be calculated satisfying Equation (11):

$$\begin{cases} s_{i,i-1} & = & r_i / N_i \\ s_{i,i+1} & = & n_i / N_i \end{cases} \tag{11}$$

Where r_i, n_i and N_i are, respectively, the number of invoices sent back for rework, the number of invoices moved forward to the next station, and the total number of invoices received on a given day. The probability ($s_{i,i}$) can easily be calculated from the other transition probabilities as $s_{i,i} = 1 - \left(s_{i,i-1} + s_{i,i+1}\right)$. To illustrate the process of determining the number of cycles required to process a "*cohort*" of documents, let us assume a processing chain composed of three stations with the following transition matrix (Equation (12)):

$$P = \begin{pmatrix} 0.2 & 0.8 & 0 & 0 \\ 0.1 & 0.25 & 0.65 & 0 \\ 0 & 0.05 & 0.3 & 0.65 \\ 0 & 0 & 0 & 1 \end{pmatrix} \tag{12}$$

Using the above transition matrix, we can easily model the dynamics of invoice processing for a given number of documents. Indeed, beginning with an initial number of documents to be processed—say, 1000 units—the processing dynamics, that is, the number of invoices at each station as a function of time, can be represented as in Figure 4-9(a). The introduction of new processing policies within the lean manufacturing framework will change the transition probabilities, and hence the dynamics of the system.

From a mathematical standpoint, the dynamics of the invoice processing chain as described by the transition matrix in Equation (12) belong to a well-known family of discrete linear problems for which exact solutions can be obtained. In the context of Equation (10), the solution in question can be expressed formally in terms of the diagonal representation of p satisfying Equation (13),

$$X_k = (P^T)^k \ X_0 = \left(Q \quad D^k \, Q^{-1}\right) X_0 \tag{13}$$

In which:

$X_k = \left[\#S_{1,k}, \#S_{2,k}, \cdots, \#S_{n+1,k}\right]^T$ is a column vector whose elements are the number of invoices at each station after k cycles (days) of processing

Q is the matrix containing the eigenvectors of the matrix P^T

D is the diagonal matrix containing the eigenvalues of P^T

Note that the closed analytical form of the solution of the linear discrete dynamic setup describing the document processing chain of Equation (13) is given by Equation (14):

$$\begin{cases} S_{1,k} &= \left(\quad 0.2825\times 0.5783^k + 0.2911\times 0.2707^k + (-1)^k \times 0.4263\times 0.9901^k \right)\times N \\ S_{2,k} &= \left(\quad 0.1069\times 0.5783^k + 0.2059\times 0.2707^k - (-1)^k \times 1.2747\times 0.9901^k \right)\times N \\ S_{3,k} &= \left(\quad 2.4965\times 0.5783^k - 4.5730\times 0.2707^k + (-1)^k \times 2.0766\times 0.9901^k \right)\times N \\ S_{4,k} &= \left(-3.8478\times 0.5783^k + 4.0759\times 0.2707^k - (-1)^k \times 1.2282\times 0.9901^k \right)\times N \end{cases} \tag{14}$$

In which N is the initial number of documents at the first station, that is, $k = 0$. Before concluding this section, it is worth mentioning that although the curves in

Figure 4-9(a) are all convergent (meaning that as the number of days (cycles) is increased the number of documents at the stations between the first and last will tend toward zero), the speed as well as the dynamics can differ according to the transition probabilities. Indeed, when the number of reworked invoices increases, the process seems to oscillate at first before decreasing monotonically, as in Figure 4-9(b). This figure corresponds to the transition matrix in Equation (6) where $s_{32} = 0.85,\ s_{3,3} = 0.1$ and $s_{3,4} = 0.05$.

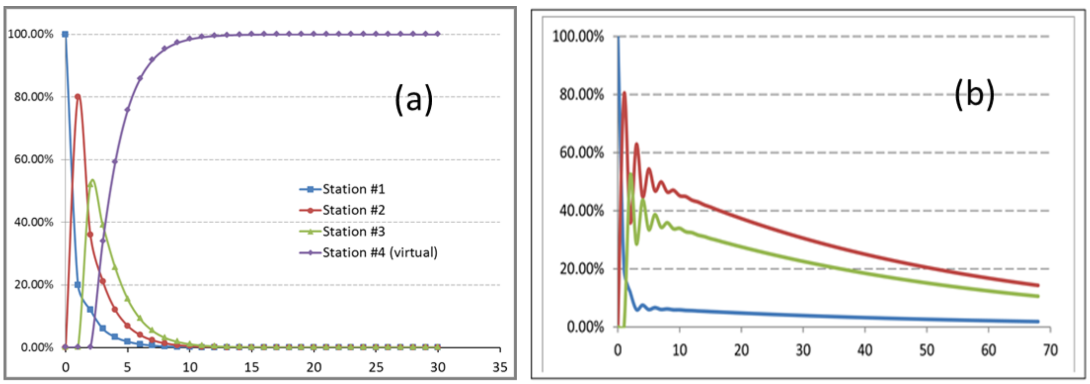

Figure 4-9 (a). Invoice processing dynamics; (b). Invoice dynamics profile for large rework rate.

The second feature worth illustrating is the concept of bottlenecking, which occurs when the speed of processing at a given station is far lower than that of other stations. According to Equation (15) and Figure 4-10(a), it is clear that the function describing the percentage of invoices at Station #1 is monotonously decreasing, an indication that a bottleneck cannot occur at this stage. Of course, since the virtual station is an absorbing state, it cannot impact the flow dynamics along the processing chain. However, a station between the first and last can create a bottleneck if it has a large retention rate, as in Figure 4-10. This figure corresponds to the transition matrix in Equation (12), where $S_{3,2} = 0.1, S_{3,3} = 0.85$ and $S_{3,4} = 0.05$.

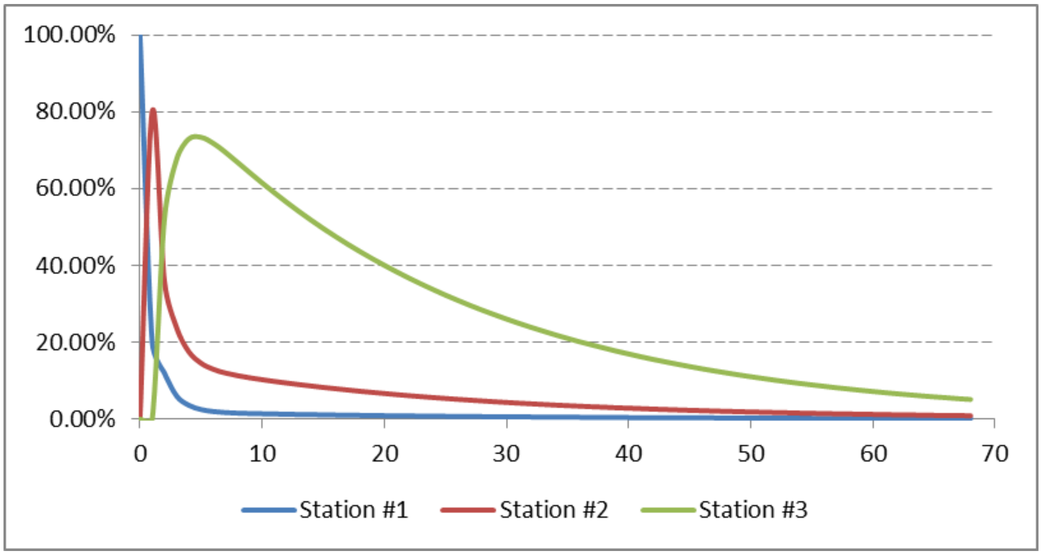

Figure 4-10. Invoice dynamics profile for large rework rate

According to Figure 4-10, a bottleneck in the processing chain is identified by a large surface under the dynamics profile of a given station. As a result, using the data depicted in Figure 4-10, one obtains:

$$B_{\mathrm{ref},j} = \frac{\sum_{k=0}^{D} k \times p_{j,k}}{\sum_{k=1}^{D} k \times p_{\mathrm{ref},k}} \tag{15}$$

Where $P_{j,k} = \frac{S_{j,k}}{N}$, j refers to the current station and "*ref*" is the station of reference (potentially the first station). In practice, the surfaces under each profile (starting at Station 2) are first in ascending order and ratios with respect to the smallest area are evaluated. At this point bottlenecks are those stations for which the ratios are far greater than 1.

Thus far, the transition probabilities in the Markov model were assumed to be constant. In practice, these values are likely to fluctuate since the throughput from one day to the next is expected to differ. In order to capture the effect of such fluctuations on the number of cycles required to process a given number of documents, probabilistic sensitivity analysis was our tool of choice, especially because of the large number of parameters (transition probabilities) involved in the model. For this purpose, the probabilities occurring in the transition matrix are sampled from appropriate probability distributions described by the density functions $f_{i,i-1}(\mathrm{t})$, $f_{i,i}(\mathrm{t})$, and $f_{i,i+1}(\mathrm{t})$. In this contribution, sensitivity analysis is carried out by means of two different approaches, referred to as the logistic-normal and best-fit methods.

4.1.2.1 The logistic-normal method

During the experimental design stage, it is often necessary for managers to make an educated guess regarding the efficiency of the processing chain. As a result, the analysis is carried out as a two-step procedure.

1. The overall transition probabilities are collected by interviewing employees at each station.

2. Sensitivity analysis is carried out assuming a logistic-normal distribution for the transition probabilities. In their seminal work on probabilistic sensitivity analysis, Doubilet et al. (Doubilet et al. 1985) used the logistic-normal distribution as a model for the probabilities occurring in a decision tree. Although other distribution functions are acceptable, their solution offered several practical advantages, including the potential to extract the population parameters from subjective estimates or objective data. In the context of this investigation, each station in the document processing chain is individually monitored in order to estimate the proportions $S_{i,i-1}$, $S_{i,\mathrm{i}}$, and $S_{i,i+1}$ that are estimates of the transition probabilities of the population $S_{i,i-1}$, $S_{i,\mathrm{i}}$, and $S_{i,i+1}$. Using the normal approximation for a binomial distribution, which holds true for large sample sizes, the 95% confidence intervals are calculated satisfying Equation (16):

$$p = \hat{p} \pm 1.96\sqrt{\frac{\hat{p}\left(1-\hat{p}\right)}{n}} \tag{16}$$

Where $\hat{p}$ is a generic symbol representing any of the proportions of interest, namely $\hat{s}_{i,i-1}$ or $\hat{s}_{i,i+1}$, and n is the sample size, that is, the amount of data collected at station i. To determine the population parameters of the normal distribution approximating the logistic-normal counterpart, we follow the prescription of Doubilet et al. (1985), which in the interest of completeness is summarized in the following equation:

- If $\hat{p} \neq 0.5, 0.025$ and 0.975 then

$$\mu = \frac{B - E\sqrt{B^2 - M^2 + \left(M \times E\right)^2}}{1 - E^2} \tag{17}$$

Where:

$$M = \log\left(\frac{\hat{p}}{1-\hat{p}}\right),\quad B = \log\left(\frac{b}{1-b}\right)$$

In which b is either the lower or the upper bound of the confidence interval width and $E = 1.96 / \Phi^{-1}\left(\hat{p}\right)$(where Φ^{-1} is the inverse of the standard normal distribution). Note that the values of the mean and standard deviation change slightly depending on the bound used during the calculation.

- If $\hat{p} = 0.5$ then $\mu = 0$.

- If $\hat{p} = 0.025$ or 0.975then $\mu = \left(M^2 + B^2\right) / \left(2 \times B\right)$.

The standard deviation σ is calculated according to Equation (18).

$$\sigma = \frac{|\mu - B|}{1.96} \tag{18}$$

4.1.2.2 Best-fit method

For the best-fit method, data is first collected, from which the overall transition probabilities are estimated. In addition to this, the data will serve to determine appropriate distributions for the transition probabilities. These distributions will then be used to determine confidence intervals for invoice lead times. The task of fitting a probability density function (PDF) to a given dataset is usually performed using an appropriate statistical test. For the purpose of this work, the Anderson-Darling approach has been selected because it is well known to be superior in predicting the PDF—especially in the case of a skewed distribution—since this test puts its emphasis on the tail of the distribution (Love et al. 2013). However, in instances where the tail does not seem to play an important role, as is the case when the data is likely to be uniformly distributed, we rely on the Kolmogorov-Smirnov test (Love et al. 2013). Before proceeding any further, it is important to mention that relying solely on the statistical test to choose a PDF may lead to unacceptable results during sampling since the transition probabilities are bound to the interval [0%, 100%]. As a result, to be acceptable for modeling the elements of the transition matrix, selected PDFs must also satisfy the probability constraints $P(X < 0) \approx 0$ and $P(X > 100) \approx 0$.

4.2 The cash flow management approach for invoice delay

Since overdue invoices are one of the strategies payers use to mitigate short-term liquidity squeezes, the research was expanded to discuss this particular strategy along with other cash flow strategies that a homebuilder can utilize to mitigate the short- and long-term cash flow risk. Due to the complex nature of project acquisition and the sensitive housing market, maintaining a healthy financial company in the homebuilding industry is a challenge. For major homebuilders, the challenge starts with reliably predicting the cash flow considering their dynamic schedule of hundreds of homes under construction, lots under development, and finished homes waiting to be occupied. Market behaviour is another factor as well as agreements with banks, homeowners, and developers. Such an environment will severely impact the efficiency of short- and long-term financial planning. As mentioned in the introduction, this research presents a financial support model for homebuilders to smooth out unfavourable fluctuations in the predicted cash flow. Here in this discussion, the author begins by presenting the methodology proposed to achieve this objective, and then supplies a case study to illustrate.

The aim of developing such a model is to enable the user to select the most efficient cash flow strategy to produce a more favourable cash flow scenario when needed (See Figure 4-11). This model allows for sensitivity analysis that takes into account constraints and options available to the user at the time of running the model. The model needs to satisfy (1) the bank by keeping the cash flow below the credit limit, (2) the developer by negotiating a win-win payment schedule that fits both the developer and the homebuilder's cash flow, (3) the contractor by paying invoices on time or delaying within acceptable limits, (4) the owner by delivering the home on time, and (5) the business by maintaining a production plan that responds to market conditions. The model enables the user to browse among cash flow strategies and examine the efficiency of each through a tradeoff analysis between the resulting cash flow and the strategy's relevant constrains.

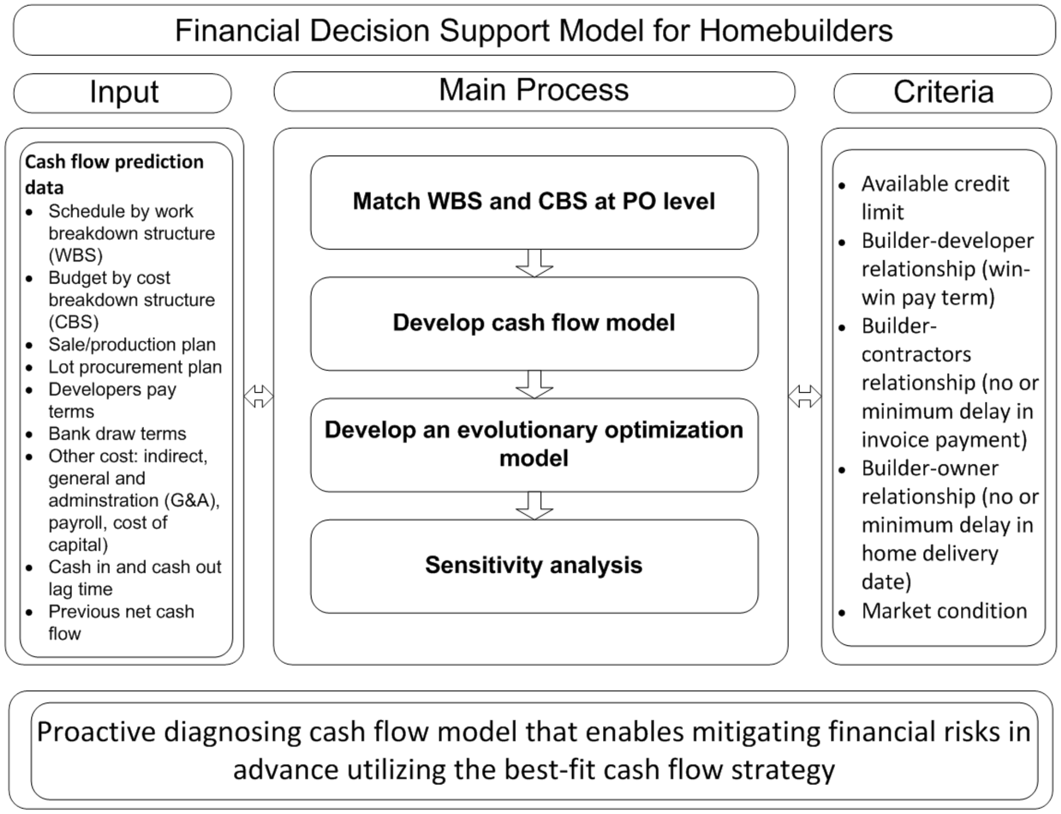

Figure 4-11. System main process

Building a reliable cash flow prediction model is a crucial step towards the overall finance-based support decision model. Understanding the complex acquisition process of a home and its contributing factors is key to developing a prediction model. As a production homebuilder, the cash receipts are primarily bank progress draws, while disbursements include land- and job-related costs (direct costs), payrolls, and company overheads. Figure 4-12 illustrates a typical home building project from buying the lot to possession date. A home building project consists of 3 phases: (1) is the development phase that starts once the lot purchasing agreement is signed with the developer and ends when a contract is signed with the homeowner to build the home; (2) is the building phase that ends at possession date; and (3) is the possession phase that starts at the possession date and includes repair cost and held cost such as lien-related or seasonal work. At any time for a major homebuilder, the cash flow includes hundreds of lots in the developing stage for homes to be built later on, hundreds of homes already under construction, and other homes (speculation and show homes) as inventory waiting to be sold.

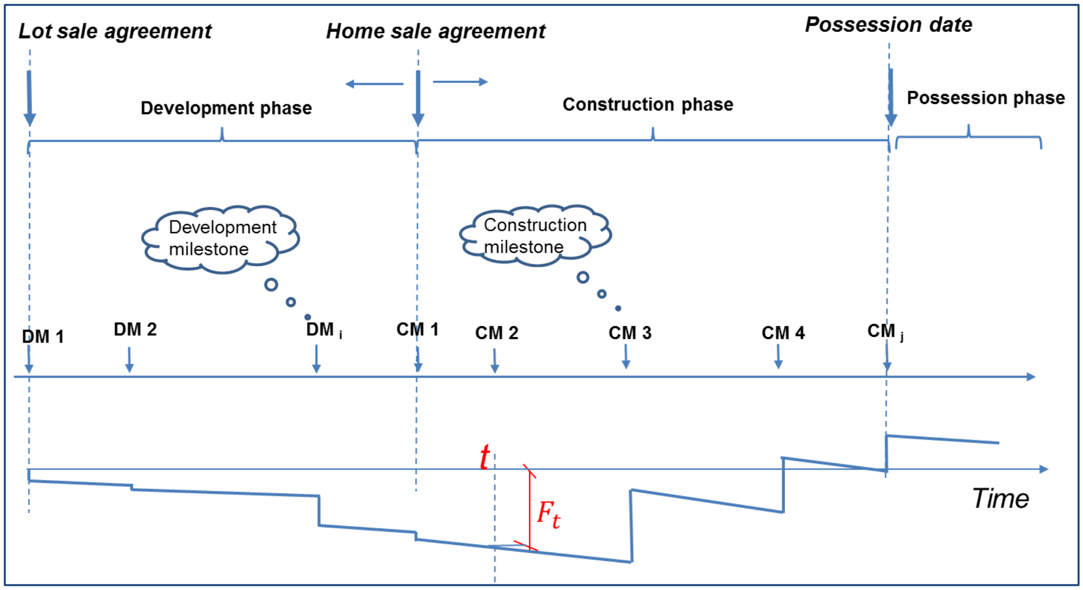

Figure 4-12. The cash flow reflecting home building phases

In the majority of cases, cash flow modeling for construction projects needs to be performed on specific time intervals matching the company-bank agreement on interest payments. For instance, for a company making financial transactions every D day, for example, weekly, bi-weekly, monthly or semi-monthly, cash flow at the end of the *t-th* period can be depicted according to Figure 4-13.

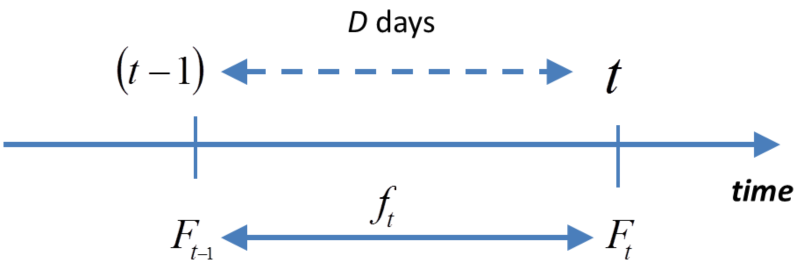

Figure 4-13. Cash flow at the end of period t

Based on the above diagram, cash flow F_t at the end of *t-th* period can be expressed satisfying Equation (19):

$$F_t = (F_{t-1} + f_t)(1 + \beta_t\, i) \tag{19}$$

In which F_{t-1} and F_t are respectively the cash flows at the end of period $(t-1)$ and t whereas f_t represents the transaction amounts (cost) incurred during the same period. As for β_{t-1}, it is an *impulse* function introduced to allow the interest rate i to be applied to the cash balance $F_{t-1} + f_t$ only when the latter is negative.

$$\beta_{t-1} = \begin{cases} 0 & \text{if } F_{t-1} + f_t \geq 0 \\ 1 & \text{if } F_{t-1} + f_t < 0 \end{cases} \tag{20}$$

Note that the cost f_t corresponding to period *t* can be expressed in terms of daily cash in- and outflows satisfying Equation (21):

$$f_t = \underbrace{\sum_{d=1}^{D} if_{t,d}}_{if_t} + \underbrace{\sum_{d=1}^{D} of_{t,d}}_{of_t} = \sum_{d=1}^{D} \left(if_{t,d} + of_{t,d} \right) \tag{21}$$

In which if_t and of_t are, respectively, the cash in- and outflows during period *t* which can be written as the sum of their daily counterparts $if_{t,d}$ and $of_{t,d}$. In the context of homebuilders, the cash outflow can further be broken down into three major contributions: (1) the development outflow dof_t representing land financing, (2) the construction out-flow cof_t corresponding to the cash required for construction, and finally (3) the overhead outflow oof_t which contains any expense related to running the organization, for example, payroll and general and administration (G&A) costs. Formally the cash outflow of_t can be written satisfying Equation (22),

$$of_t = dof_t + cof_t + oof_t \tag{22}$$

Where dof_t, cof_t and oof_t are, respectively, the development, the construction, and the overhead outflows. According to Figure 4-13, it can be seen that during the development phase, that is, land financing, the homebuilder does not pay the full price of land at once. Instead, payments are required to be made at specific times referred to as Development Milestones (DMs). Consequently the development cash outflow for period *t* (comprising *D* days) is expressed as the sum of daily cash outflows dof_d and can formally be written satisfying Equation (23),

$$dof_t = \sum_{d=1}^{D} dof_d = \sum_{d=1}^{D} \left(\sum_{l=1}^{m} \sum_{i=1}^{u} C_{l,i}^{DM}\left(x_{l,i}\right) \left\langle d - x_{l,i} \right\rangle^0 \right) \tag{23}$$

Where $C_{l,i}^{DM}\left(x_{l,i}\right)$ is the development milestone i for lot l, which is due on date $x_{l,i}$. As for the term $\left\langle d - x_{l,i} \right\rangle^0$, it is known as a discrete singularity function defined according to Equation (24) (Lucko 2013):

$$\left\langle d - x_{l,i} \right\rangle^0 = \begin{cases} 1 & \text{if } x_{l,i} < d \\ 0 & \text{if } x_{l,i} \geq d \end{cases} \tag{24}$$

Similarly, the construction cash outflow, cof_t, can be expressed as a sum of daily construction cash outflows cof_d (during period t) which depend on the construction schedule, where start and finish dates for every activity are clearly recorded. However, for the purpose of cash outflow on a given day d, the most relevant parameters are the finish date of the activities, which is related to the lag time as, $(d - I_{gt})$ and their cost as described in the PO. For the purpose of numerical experimentations and optimization, cof_t is defined satisfying Equation (25),

$$cof_t = \sum_{d=1}^{D} cof_d = \sum_{d=1}^{D} \left(\sum_{p=1}^{n} \sum_{a=1}^{w} C_{p,a}^{CA}\left(f_{p,a}^{CA}\right) \left\langle d - \left(f_{p,a}^{CA} + I_{gt}\right) \right\rangle^0 \right) \tag{25}$$

Where $C_{p,a}^{CA}\left(f_{p,a}^{CA}\right)$ is the cost (invoice amount) associated with construction activity a, for project (home) p, scheduled to be completed on day $f_{p,a}^{CA}$. Here, it is important to note that Equation (25) can be linked to the invoice lead time I_{lt} since the term referred to as invoice lag time can be written as:

$$I_{gt} = (I_{bt} + I_{lt}) \tag{26}$$

In which I_{bt} is known as the billing time, which is the time between the time (day) an activity is completed and the time the invoice is received by the owner (Figure 4-14). For the purpose of the quantitative analysis described in the next section, we have used $I_{bt} = 10$ business days (i.e., two weeks), which represents the average lag time observed in the case study. The last component of the cash outflow is the overhead disbursements, which include payroll and General and Administration (G&A) costs, which are assumed to be constant. This term can be estimated by using recent historical data for G&A and the predicted staff plan.

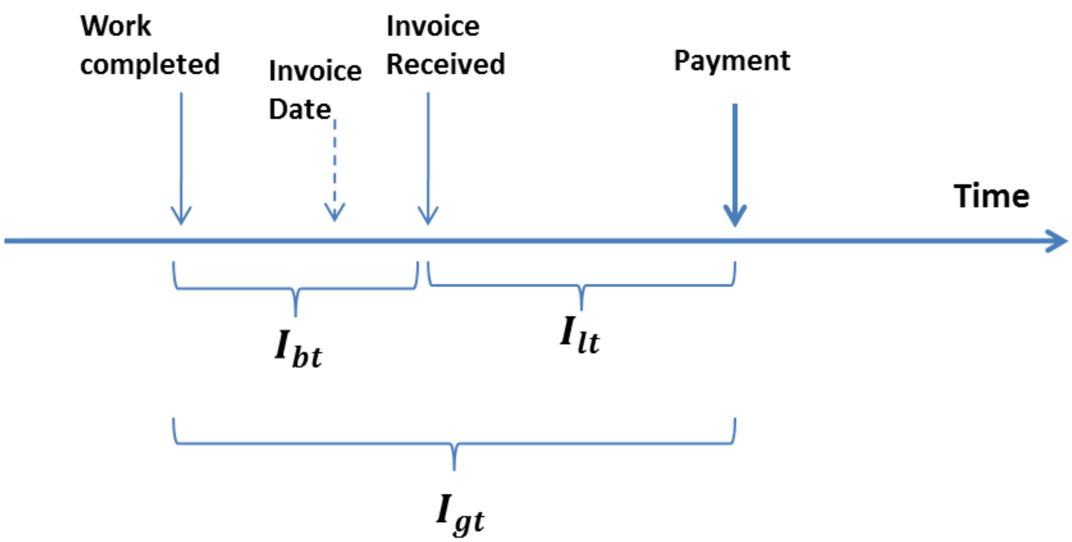

Figure 4-14. Invoice lag time

As for the cash inflow part, a bank draw, which is a ratio of the home price, is triggered once a relevant milestone is reached. For the sake of reducing the complexity of the model, the construction milestones list is assumed to be consistent through the different banks' agreements even though the draw amount for similar milestones may vary from one agreement to another. Six construction milestones (CM) are considered in this model: (1) contract signing with the homeowner, (2) construction start, (3) framing completion, (4) painting completion, (5) possession date, and (6) release of lien hold. Therefore, the cash inflow value at the end of period t is represented satisfying Equation (27),

$$if_t = \sum_{d=1}^{D} if_d = \sum_{d=1}^{D}\left(\sum_{p=1}^{n}\sum_{k=1}^{6} B_{p,k}^{CM}\left(y_{p,k}^{CM}\right)\left\langle d - y_{p,k}^{CM}\right\rangle^{0}\right) \qquad (27)$$

In which $B_{p,k}^{CM}\left(y_{p,k}^{CM}\right)$ is the bank draw corresponding to construction milestone k for project (i.e., home) p due on day $y_{p,k}^{CM}$. In deriving the cash flow given in Equations 19 to 27, the production plan, which at the high level may be viewed as a list of projects (i.e., homes) with their anticipated start dates, is assumed to be fully known. In other words, changes in the production plan not only will be reflected in the cash flow models, but, more importantly, strong deviations may be observed between different production scenarios. In this context, it will be shown that the equations given above will help project planners to easily explore different production plans (based on the market and resource constraints) to determine the scenario that leads to the most appropriate cash flow profile. In the case of homebuilders who specialize in large throughput construction, namely those who do not build custom housing, the duration of each activity for their model homes can be derived from historical data. As a result, an integrated information modeling system can be engineered which, when given the start date of a project (i.e., home), automatically generates the construction schedule; this in turn will serve to build a cash flow profile. Here, it is important to note that since construction activities are fraught with uncertainty, it is necessary to have a mechanism, albeit elementary, allowing the information system to capture this aspect of activity scheduling in order to be able to propagate it to the cash flow profile. In this thesis, uncertainties are taken into account by the introduction of a time factor, referred to as the lag time between activities, which is particularly critical for sequential tasks. Figure 4-15(a) presents an example of start-start relationship between two sequential activities. Other relations in Figure 4-15(b) and Figure 4-15(c) are finish-start and finish-finish.

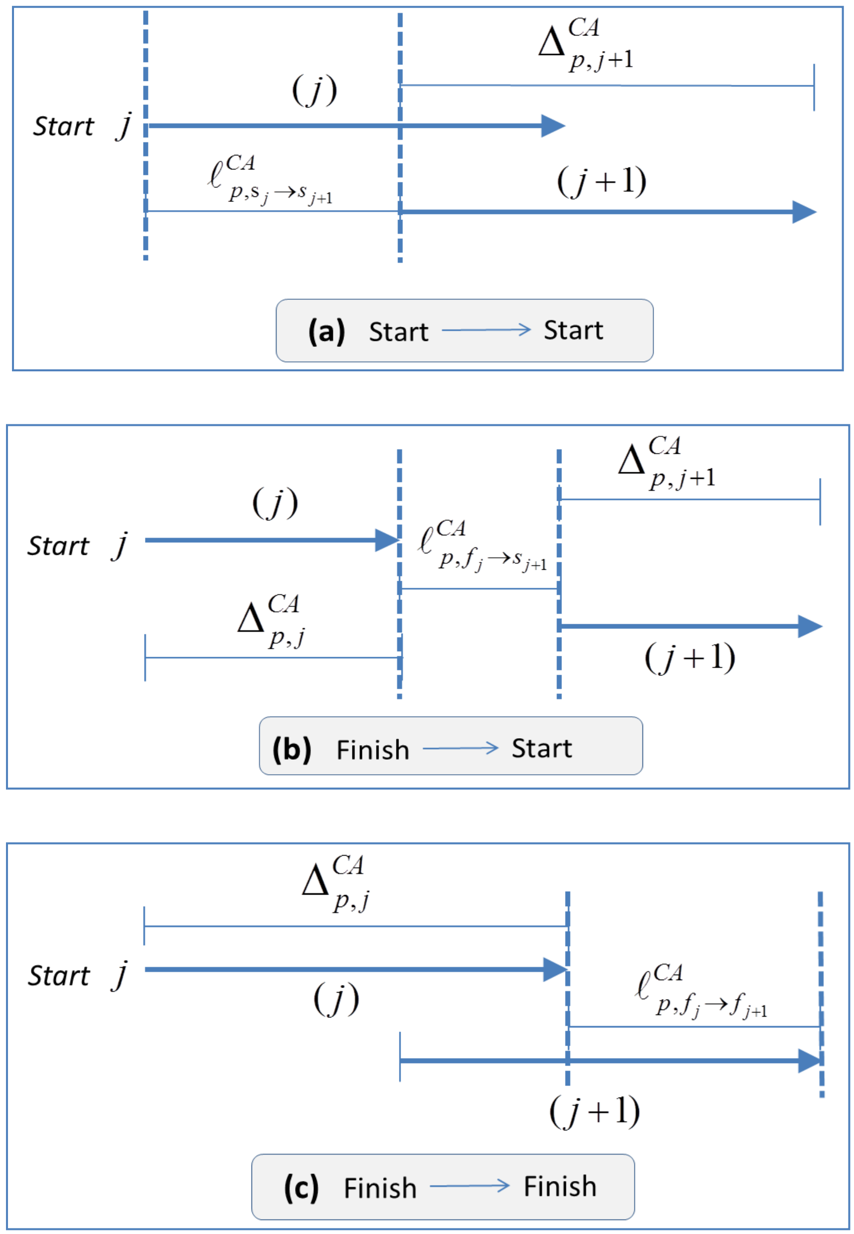

Figure 4-15. Relationship scenarios between sequential activities j and $(j+1)$: (a) start to start, (b) finish to start, and (c) finish to finish

Using Figure 4-15, the finishing date ($f^{CA}_{p,j+1}$) of task $(j+1)$ given starting date of task j and relationship type can be written satisfying Equations 28 to 30,

$$Finish\,to\,start: \; f_{p,j+1}^{CA} = S_{p,j}^{CA} + \Delta_{p,j}^{CA} + \Delta_{p,j+1}^{CA} + \ell_{p,f_j \to s_{j+1}}^{CA} \quad (28)$$

$$Start\,to\,start: \; f_{p,j+1}^{CA} = S_{p,j}^{CA} + \Delta_{p,j+1}^{CA} + \ell_{p,s_j \to s_{j+1}}^{CA} \quad (29)$$

$$Finish\ to\ finish: \; f_{p,j+1}^{CA} = S_{p,j}^{CA} + \Delta_{p,j}^{CA} + \ell_{p,f_j \to f_{j+1}}^{CA} \quad (30)$$

In which $S_{p,j}^{CA}$ is the starting date of construction activity *j* in project *P*, $\Delta_{p,j}^{CA}$ and $\Delta_{p,j+1}^{CA}$ are the duration of construction activity *j* and $(j+1)$ of project *P*, while $\ell_{p,s_j \to s_{j+1}}^{CA}$, $\ell_{p,f_j \to s_{j+1}}^{CA}$, and $\ell_{p,f_j \to f_{j+1}}^{CA}$ are, respectively, the start-start, finish-start, and finish-finish lag time between sequential activities. As mentioned above, the lag time in Equation (28) is introduced as a means to include uncertainties in the scheduling process since this parameter is determined based on statistical analysis of historical data from which the value of $\ell_{p,s_j \to s_{j+1}}^{CA}$ was determined to accommodate 95% of the cases for each model home offered by the homebuilder.

To close this chapter, it is important to mention that large throughput homebuilders build two types of houses: (1) pre-sold homes, where a contract is signed between the builder and the homeowner prior to starting the construction, and (2) speculation houses, which are totally financed by the builder if no buyer is found during the construction period. Speculation houses are usually constructed when: (1) the market for new homes shows temporary signs of slowing down but is anticipated to regain strength in the very near future; (2) to respond to the various demands of customers in terms of possession date; and (3) to level resources when needed. In this contribution, we have examined the case of pre-sold houses for which there are cash inflows in the form of bank draws from the homeowner at each of the six construction milestones described above.

Chapter 5 - Case Studies

The case studies were selected to cover different scenarios pertaining to invoice processing systems. The organization of this chapter reflects the framework presented in Chapter 4, in which a dual-approach methodology (invoice processing and cash flow management) was proposed to manage construction invoices more efficiently.

5.1 The invoice processing approach-case studies

As explained in the methodology chapter, two methods were proposed to minimize invoice delay: integrated lean and DES and Markov modeling.

5.1.1 The integrated lean and discrete event simulation

Two case studies were analyzed for this approach. The main objective is to examine the efficiency of the proposed methodology in two different invoice-processing systems. The first belongs to a major oil and gas company that implemented a state of the art electronic invoice processing system as a part of an Enterprise Resource Planning system (ERP), which is a system that facilitates the information flow between all business functions (finance/accounting, procurement, project controls, etc.) inside the organization. The second case study examines the invoice processing system of a major homebuilder, around a quarter the size of the first company, which has a manual invoice processing system with minimal integration of an accounting system in the downstream of the process.

5.1.1.1 Case study 1: Oil and gas company

A summary of the descriptive statistics obtained in the case study for this research provides a clearer idea of the extent of the overdue invoice problem. The overdue invoice issue encountered in the case study is typical of many sectors of the construction industry, although these statistics are specific to a single case. The unknown, however, is the extent of the issue and its impact on profit and reputation. Based on data collected from one of the industry partners, in Table 5-1 the researcher has summarized the number of invoices received each year between 2008 and 2010 and the corresponding numbers of overdue invoices. Between 2008 and 2010, approximately 45% of the processed invoices were overdue, that is, had not been paid within the pay term.

Table 5-1: Number of aged invoices between 2008 and 2010 for the industry partner

Year	No. Invoices	Ratio of Overdue Invoices
2008	77,349	47%
2009	89,606	46%
2010	70,008	42%
Average	78,988	45%

Data in Table 5-1 shows an alarmingly high rate of overdue invoices in 2010 despite evidence of improvement compared to 2008. Data of overdue invoices can be segregated by service type (engineering, construction, or material supply), or by contractor within service type. It should be noted that the observed improvement for this particular partner was essentially achieved by introducing an electronic system. However, using an electronic system only allowed for a marginal gain, because the processing flow remained unchanged.

Seasonality is another factor affecting the construction industry. This reality is particularly evident in the Alberta context, where severe weather conditions (cold winters) are synonymous with decreased numbers of new projects. The author thus proceeded with an investigation into the number of invoices as a function of seasonality. The motivation for this component of the investigation was twofold: (1) forecasting the number of documents that need processing in a given month allows managers to request the appropriate level of resources to keep processing flowing smoothly (minimizing the number of overdue invoices), and (2) studying the impact of seasonality on the number of invoices provides an approximate idea of cash demand throughout the year. Figure 5-1 shows an analysis of the data from one of our industry partners (covering the period 2008 to 2010) as a time series.

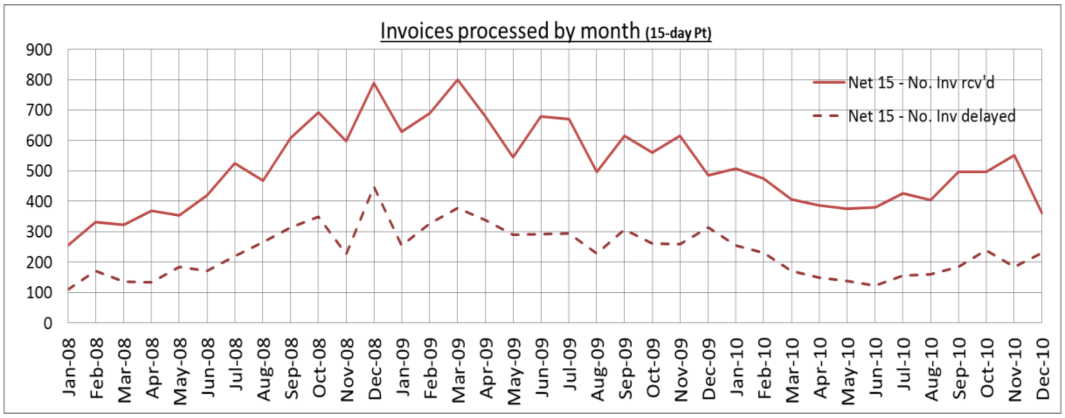

Figure 5-1. Net-15 invoices processed monthly between 2008 and 2010

The peaks in overdue invoice ratios following peaks in received invoices in Figure 5-1 shows a high correlation between overdue invoices and the volume of invoices received. In other words, there is no planned change to the document processing protocol to respond to increased demand. This can be avoided if a chart similar to that in Figure 5-1 could be forecasted, from which resources and possibly process design could be better planned. In this regard, predictions of future demand (i.e., number of invoices received) is possible with statistical tools like regression. Simic et al. (2009), for instance, used eight years of invoice history to predict invoices and cash outflow. Of course, in order to increase the accuracy of the regression model it is important to have a sufficiently large dataset (more than three years), but, more importantly, data that is descriptive of the same general economic situation. In this respect, the spike (economic boom time) that occurred in Alberta between 2005 and 2008 can be considered an outlier.

In 2010, 44 pay terms were used, eight of which are presented in Figure 5-2 with the ratio of invoices received for each pay term. The pay terms presented in

Figure 5-2 represent 98% of invoices received. No significant change in ratio of invoices received by pay term was found from 2008 to 2010.

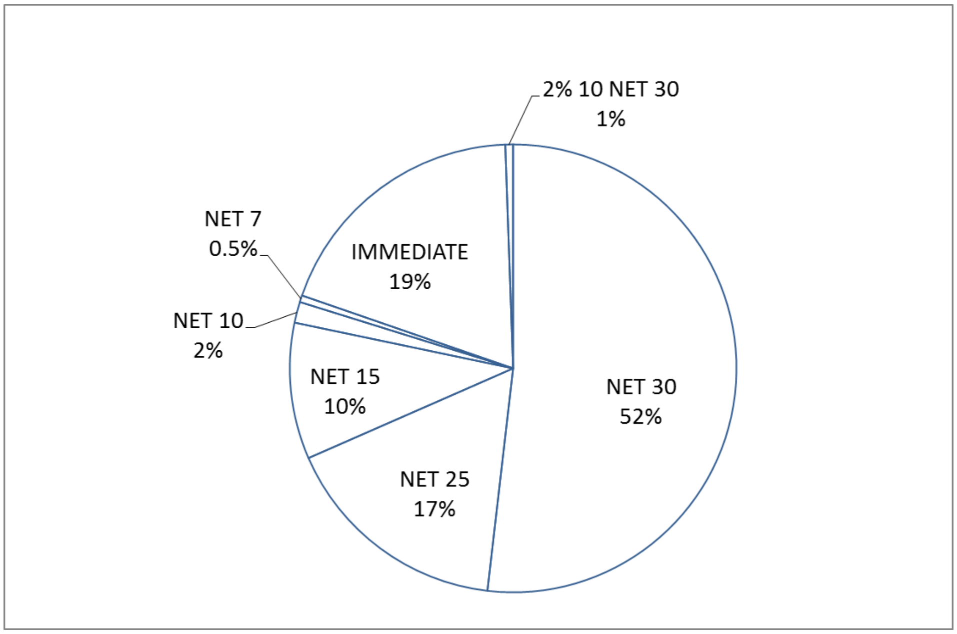

Figure 5-2. Ratio of invoices by pay term

A pay term of “2% 10 net 30” (see Figure 5-2 above) means that 2% of the invoice amount can be credited to the owner if the invoice is paid within the first 10 days of the 30-day pay term. This is an example of the strategy mentioned earlier in Chapter 3, whereby contractors offer an early payment incentive to construction owners in order to avoid greater financial loss later due to invoice payment delay on the owner side. The pay term analysis can be broken down by service (engineering, construction, or material supply) or by company. Figure 5-3 shows the ratio of invoices by pay term for (a) an engineering company and (b) a construction company. It can be concluded that pay terms can differ for the same company. More in-depth analysis was undertaken to link the different pay terms within the company to contract type or scope of work. However, no link was found. For example, an engineering company delivers multiple detailed designs based on unit rate contracts that differ in pay term. Clearly, there is a basic need to standardize pay terms starting at the company level.

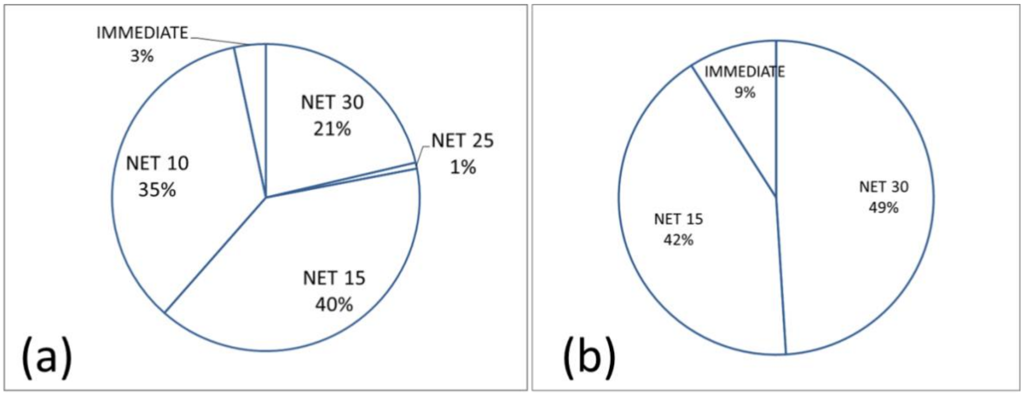

Figure 5-3. Ratio of invoices by pay term for (a) an engineering firm (b) a construction firm

To understand the risks associated with shorter pay terms better, the available historical data is segregated according to the invoice pay terms. Figure 5-4 shows the ratio of overdue invoices in each category. The risk of overdue invoices definitely exists in any pay term, but it is considerably higher for shorter pay terms than for longer pay terms. This observation is explained by the fact that invoices are processed without regard for their respective pay terms. The practical implication of analyzing their data can be instructive to owners because owners can split the process and fast-track short pay terms (e.g., up to 15 days) and keep it as is for longer pay terms.

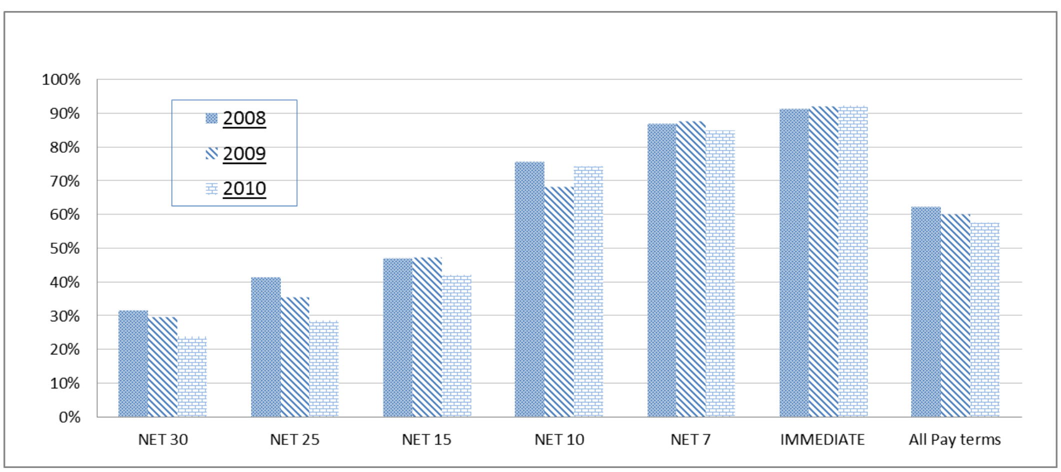

Figure 5-4. Conditional distribution of overdue invoices by pay term.

Meetings and interviews were carried out with the accounting team to build the process chart. Templates were distributed for data collection of processing time, lead-time, and rework rate at each station in order to build the C.S.VSM shown in Figure 5-5.

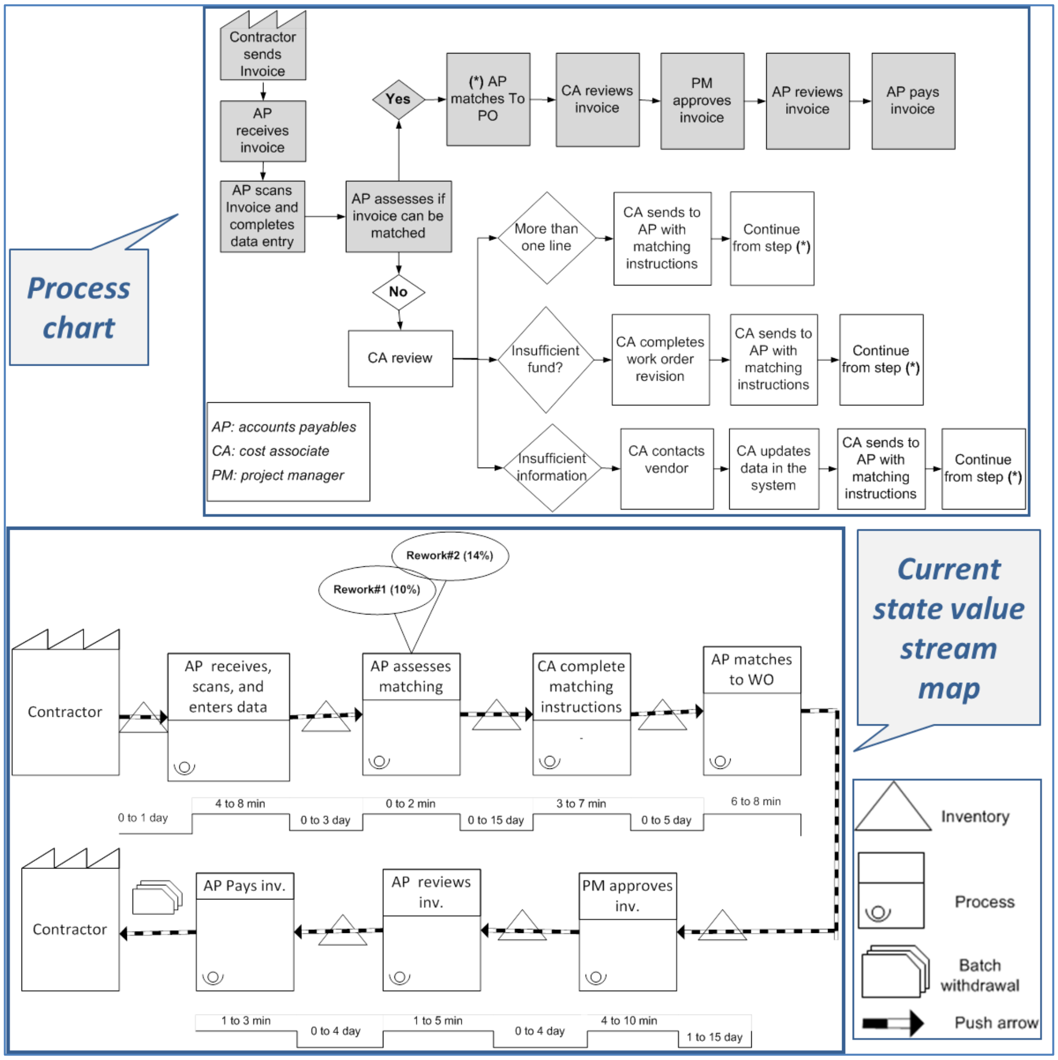

Figure 5-5: Invoice current-state value stream map (C.S.VSM)

It should be noted that the VSM presented in Figure 5-5 reflects only one branch of the process (icons in grey – process chart) and does not reflect the impact of rework. In order to address these shortcomings and to reflect the dynamic and probabilistic nature of the process, the process has been modelled in this research using Simphony.NET, a discrete event-based simulation tool developed by the

Construction Engineering & Management group at the University of Alberta (see Figure 5-6).

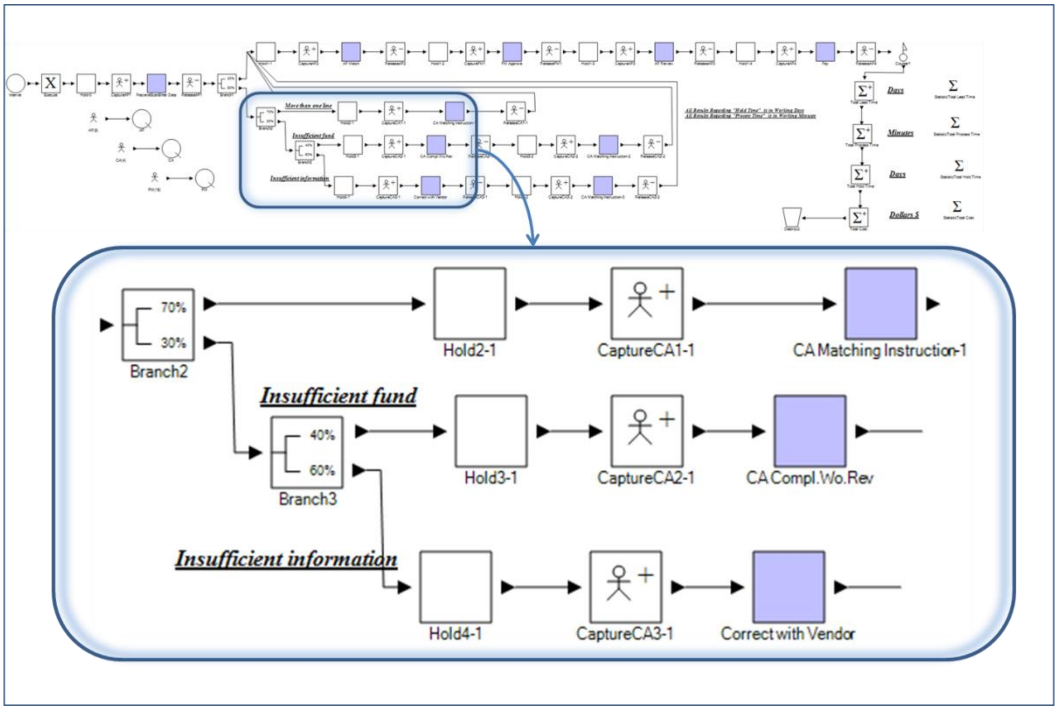

Figure 5-6: Invoice simulation model using discrete event-based simulation tool

At each station, the processing time and lead-time are calculated. Meanwhile, the impact of rework is quantified in terms of processing and lead times. For verification purposes, the distribution of invoice lead-time from the simulation results is also compared to its distribution in the historical data (see Figure 5-7). The figure shows a similar distribution, with just slight differences in the mean and the standard deviation. These differences, which are considered acceptable, are due to assumptions pertaining to the interviews with subject experts where real data could not be collected.

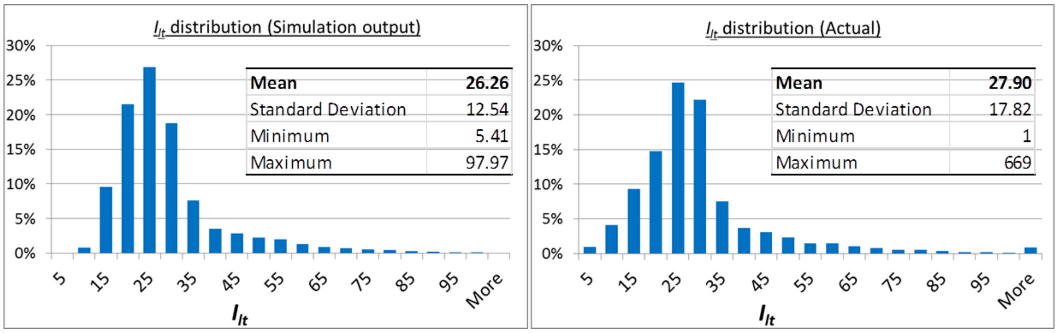

Figure 5-7: I_{lt} distribution resulting from historical data and simulation output

Based on the developed invoice process chart and the associated simulation model, the collected data is fed to the model, resulting in the following inferences:

- The average processing time resulting from the simulation model is 38 minutes per invoice, which is equivalent to approximately 50,000 hours/year for an estimated invoice volume of 80,000 invoices/year. This includes time spent by staff—including accountants, project controllers, and project managers—on processing, approving, reviewing, and signing invoices.

- The average invoice lead-time in the simulation is 26.3 days (compared to an actual average of 27.9 days). The distribution of invoices by lead-time is shown in Fig 5-7.

The next step is to analyze the invoice C.S.VSM in order to identify and quantify waste in the invoice processing time ($\mathbf{I_{pt}}$) and the effect of waiting time on invoice lead time ($\mathbf{I_{lt}}$). One type of waste analyzed in this study is waste due to rework. Rework in the invoice process can result from a number of factors, such as (1) insufficient information submitted by the vendor, and (2) inaccurate estimates and/or a lack of consistent forecasting, a problem which requires an increase in the work order value following invoice issuance. Here, further analysis can be done regarding process design, resource utilization, and bottleneck allocation.

Quantification of waste is achieved by conducting a sensitivity analysis using the simulation model in conjunction with a thorough task investigation carried out along the process. The outcomes can be seen in Figure 5-8, where improvement suggestions are introduced to the simulation model as scenarios. In Figure 5-8, an improvement in invoice lead-time can be noted between Scenario 0 (original) and Scenario 1 (no rework). The no rework scenario eliminates the root causes of rework by (1) changing the instructions to the vendor to ensure that sufficient information is attached to the submitted invoices; and (2) establishing a forecasting system that is proactive enough to take timely remedial measures, such as increasing the work order amount before the relevant invoices enter the system. Figure 5-7 also exhibits the decrease in invoice processing time as a result of the proposed improvement plan.

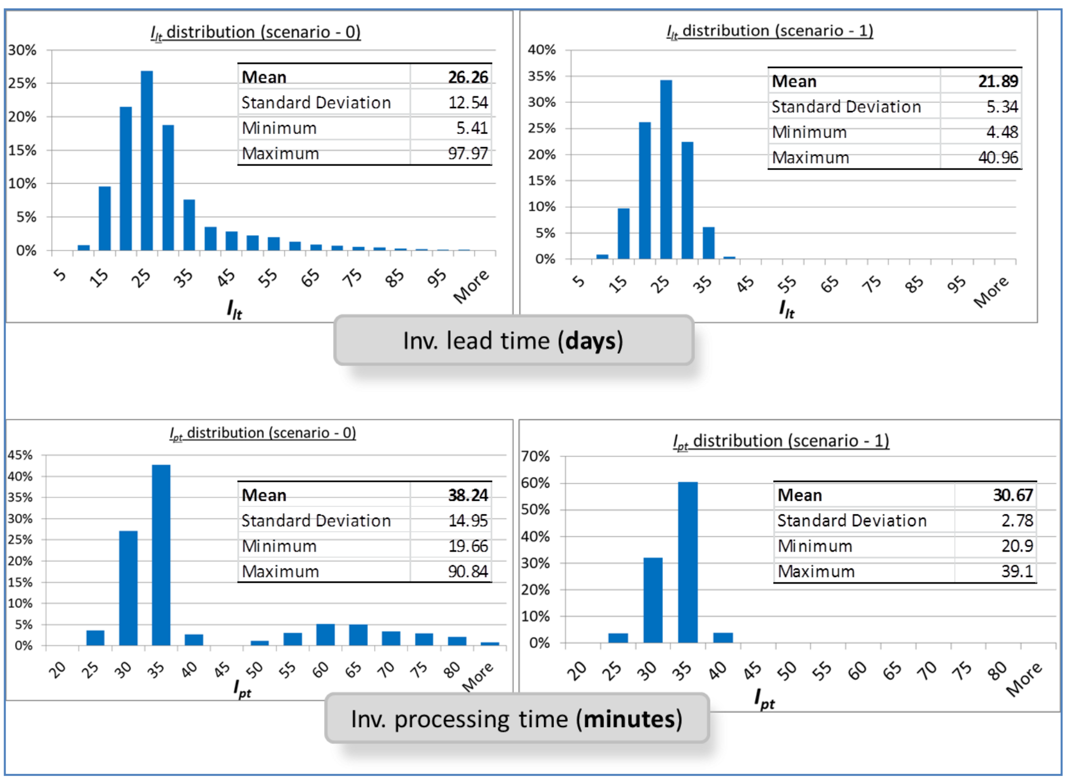

Figure 5-7: Simulation outcomes showing decreases in I_{lt} and I_{pt}

It is worth mentioning that the above analysis was carried out on an electronic invoice processing system, in which the invoice flow is fully automated from initial receipt to the payment. The picture is no different from another construction company's (case study 2), where the system is manual and 75% of invoices are aged although 90% of invoices have a 30-day pay term. Such differences are not limited to system in use (electronic or manual) or the variety of pay terms, but also to the company size, organization structure, service provided (heavy construction, residential), and procurement system.

5.1.1.2 Case study 2: Major homebuilder

This case study was conducted in collaboration with a homebuilder located in Alberta, Canada. This homebuilder annually produces more than 1,000 single homes from several models distributed between Edmonton, Calgary and Red Deer. Each of these cities has its own accounts payable system that is partially manual (receiving, checking, and approving) with all the relevant paper work (sorting, accumulating, printing, handling, archiving). The author interviewed the accounting team to build the process chart (Figure 5-9). The invoice process was divided to three major phases: check, approve, and pay. Each of these phases was broken down to tasks as a level 2 breakdown. In phase 1 (check), invoices are received as hard copies, checked and then sorted to the designated site manager. In phase 2 (approve), invoices travel to another location(s) to be approved by site managers, then return to the office building to be accumulated again and sorted as per division. While tasks are similar in both stages of the approval phase, the level 2 process chart reflects tasks completed in stage 1 only. In phase 3 (pay), invoices are sorted according to date received and contractor name, their data entered to the accounting system, and then routed for account managers' reviews and approval before paying. Also, the level 2 tasks of phase 3 shown in Figure 5-9 are only those processed for division 1.

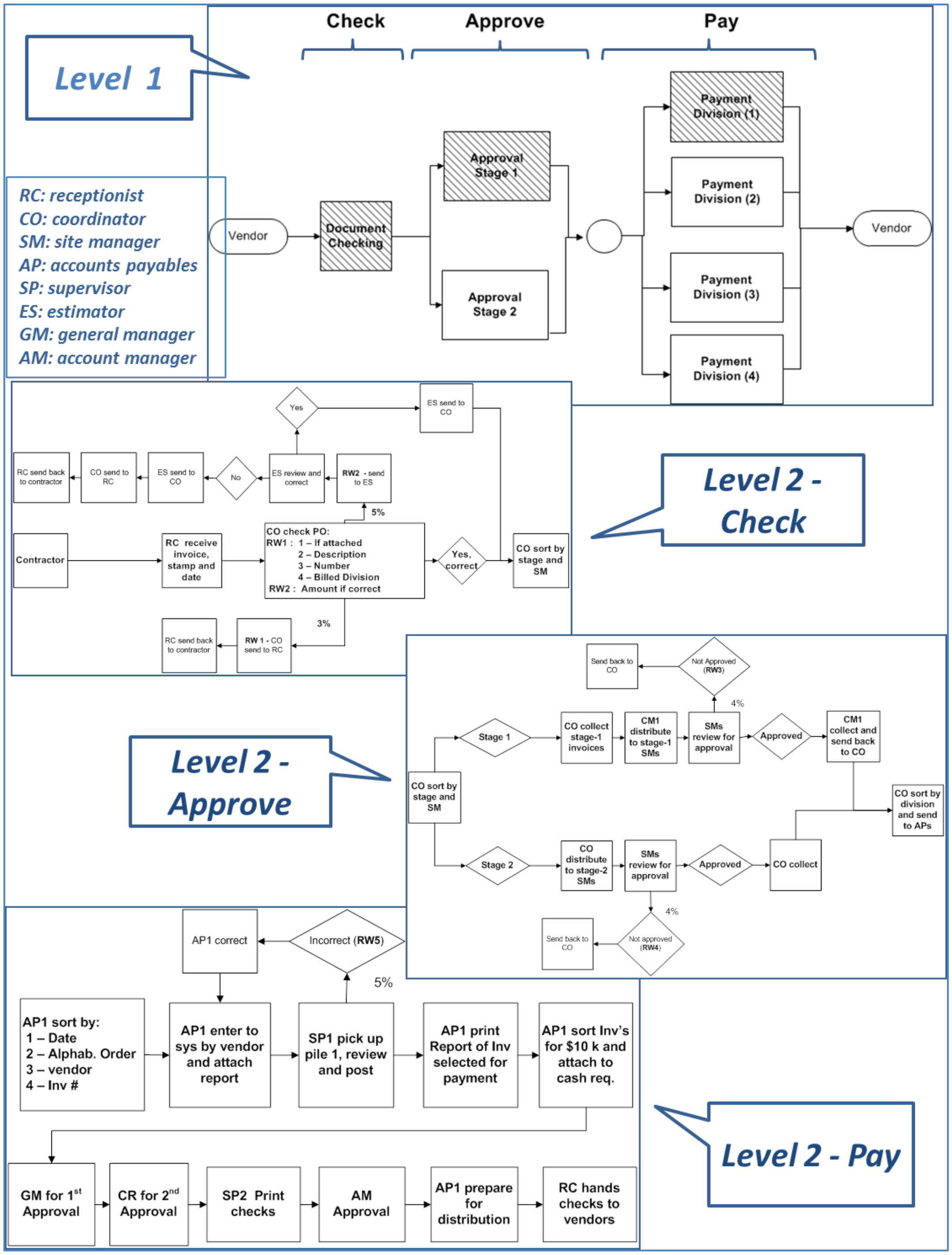

Figure 5-8: Invoice process chart divided into 3 stages (check, approve, and pay)

Templates were distributed to calculate processing time, lead time, and rework rate at each of these stations, where data collection is attainable, in order to build the C.S.VSM as shown in Figure 5-9. Other stations required interviews with personnel working on the process or using a stopwatch when a task was being performed. It should be noted that the VSM presented in Figure 5-9 reflects only one branch of the process (icons in grey – Level 1) and does not reflect the impact of rework.

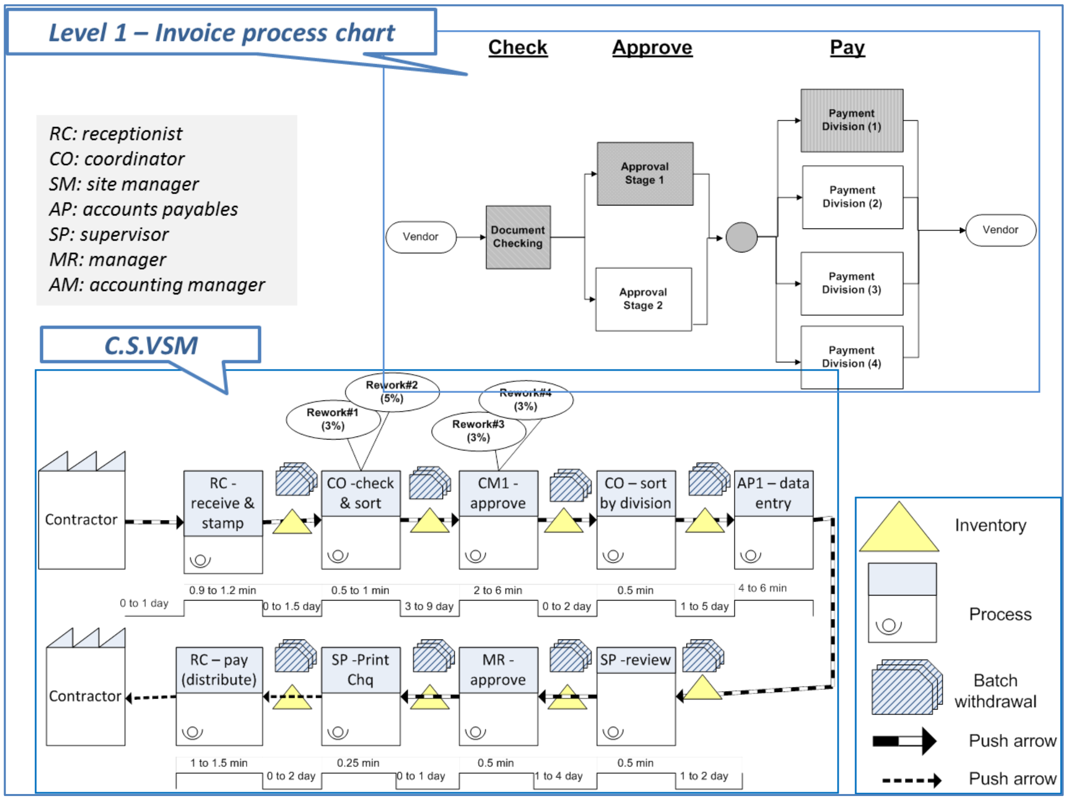

Figure 5-9: Invoice current-state value stream map (C.S.VSM)

In order to address these shortcomings and to reflect the dynamic and probabilistic nature of the process, the process has been modeled in this research using Simphony.NET (Figure 5-10). At each phase (check, approve, pay), the processing time and lead-time are calculated. Meanwhile, the impact of the batch process, inconsistent flow, rework, and back-end strategy are quantified in terms of processing and lead times. For validation purposes, the distribution of invoice lead-time from the simulation results is also compared to its distribution in the historical data (Figure 5-11). The figure shows a similar distribution, with just slight differences in the mean and the standard deviation. These differences, which are considered acceptable, are due to assumptions pertaining to the interviews with subject experts where real data cannot be collected.

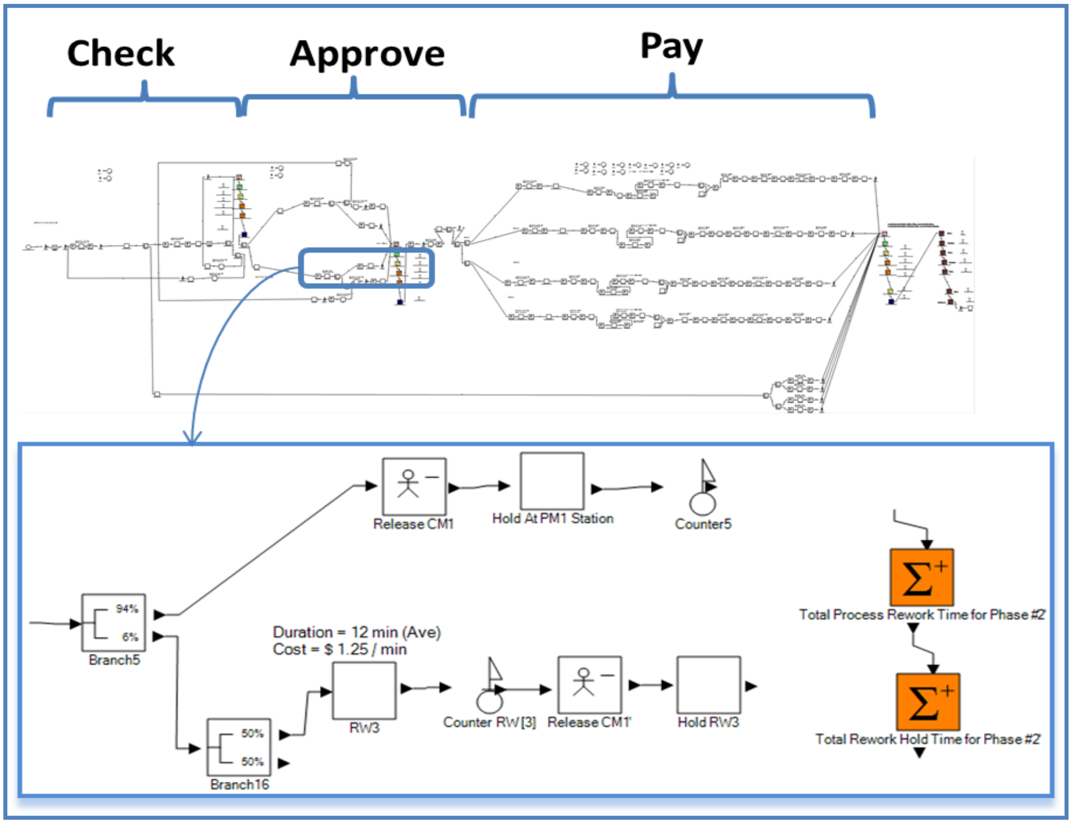

Figure 5-10. Invoice simulation model using discrete event-based simulation tool

Based on the developed invoice process chart and the associated simulation model, the collected data is fed to the model, resulting in the following inferences:

- The average processing time resulting from the simulation model is 14 minutes per invoice, which is equivalent to approximately 20,000 hours/year for an estimated invoice volume of 85,000 invoices/year. This includes time spent by staff—including receptionists, accountants, estimators, and site managers—on processing, approving, reviewing, and signing invoices.

- The average invoice lead time in the simulation is 36.3 days, which is close to the actual invoice lead time of 35.6 days. The distribution of invoices by lead time is shown in Figure 5-11.

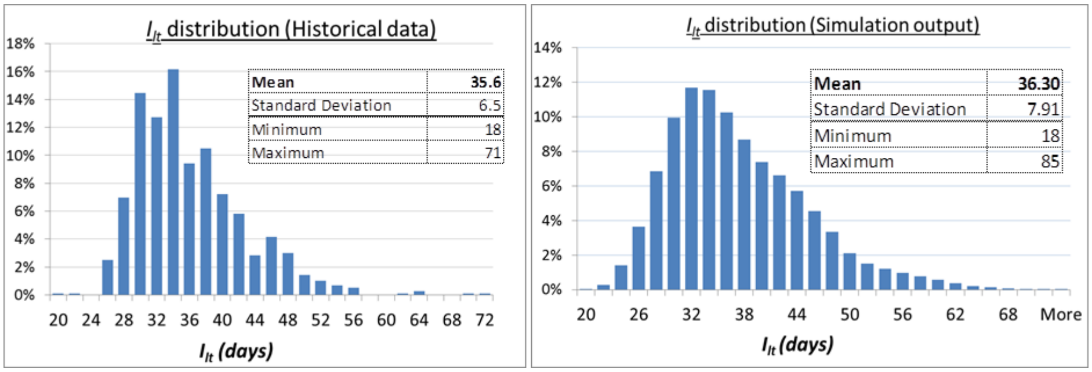

Figure 5-11: I_{lt} distribution resulting from historical data and simulation output

The next step is to analyze the invoice C.S.VSM in order to identify and quantify waste in invoice processing time (**I_{pt}**) and the effect waiting time has on invoice lead time (**I_{lt}**). Waste in the process in relation to total invoice processing time and its impact on actual hours per year are shown in Table 5-2.

Table 5-2: Categories of processing time waste

Waste description	Estimated loss of time (min/inv)	Impact per year (hour/year)	Reason	Suggested Improvement
Rework	2	2,833	Mostly due to Purchase Order (PO) variance.	Change in instructions to vendors for issues to be solved before invoice is submitted.
Manual work	2.9	4,108	Sorting and collecting activities before/after approving stage and before distribution to vendors, opening letters, handling, moving, distributing to vendors, filing, and archiving invoices.	Apply electronic invoice tracking system.This includes moving part of data entry upstream to be after the receiving station.
Unlevelled load of work	1.4	2,000	Volume of invoices is not distributed evenly to Accounts Payable employees working on divisions.	Review AP-by-division design of process. Review Accounts Payables utilization.
Total Waste impact on processing time (min)	6.3	8,941		

Quantification of the waste is achieved by conducting a sensitivity analysis using the simulation model in conjunction with a thorough task investigation carried out along the process. The outcomes can be seen in Figure 5-12, where improvement suggestions are introduced to the simulation model as scenarios. Scenario 1 assumes no rework while Scenario 2 assumes application of an electronic system that considers Scenario 1 as a new baseline. These improvement suggestions were discussed with the steering team to ensure practicality and compliance with pertinent business rules.

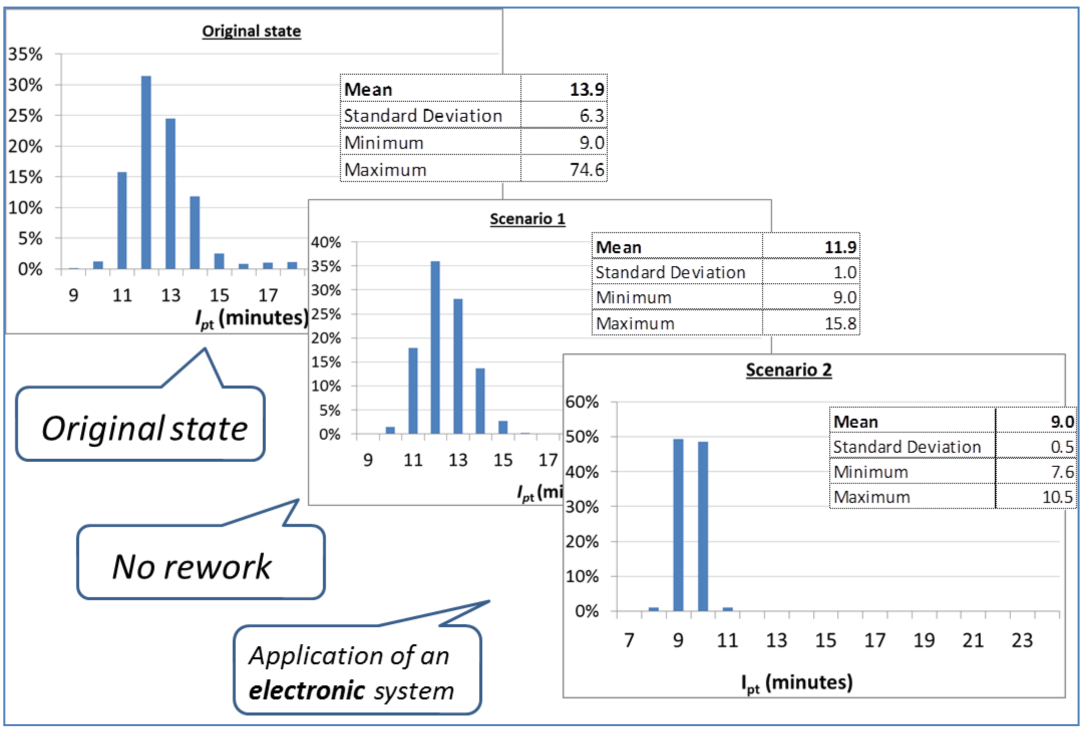

Figure 5-12. Simulation outcomes shows decrease in I_{pt}

For the workload-leveling step, Accounts Payable (AP) personnel utilization was calculated using the simulation model. The results suggest the resources involved are underused. In light of this observation, the author suggests invoices be distributed evenly to three branches instead of four divisions in the "pay" phase, reducing processing time and cost by one AP person (2000 hours/year). What is most notable in terms of lead time is that, of the mean invoice lead time of 36 days, waiting time accounts for 99.9%, with processing time (14 minutes) accounting for only 0.1%. These observations were carried out at each station along the process. For example, in order to calculate waiting time in a station, a representative sampling of invoices was flagged and the time was recorded at the start and end of the invoice process for each station. As a result, the causes of invoice waiting time were categorized, and their respective contributions to invoice lead-time estimated (see Table 5-3). Improvement ideas, along with their corresponding implementation timeframes, were suggested and introduced to the simulation model (see Figure 5-13). Scenario 1 reflects the invoice process assuming zero rework, while Scenario 2 assumes that an electronic system is in place, thus eliminating the need for a control station. Figure 5-13 shows a decrease in $\mathbf{I_{lt}}$ from 36 to 13 days.

Table 5-3: Waiting time categories

Waiting time description	Contribution to average waiting time (day/Inv)	% Contribution to lead time	Reason	Suggested Improvement
Rework	2	6%	Mostly the Purchase Order (PO) variance. Invoice need to be sent back to estimators	Revise vendor invoice requiremnets that includes clear instructions in order to increase accountability at the vendor level
Batch effect	14	39%	Batches are accumulated at every station. Invoices needs to wait until batch is complete and then move to the next station	Electronic system imposes continuous flow of invoices and eliminates queue time
Inconsistent flow of coming invoices	2	6%	Vendors tend to submit there invoices at the mid and end month cut off. This creates queue times especially in the upstream stations.	Establish a pace maker upstream and apply electronic system imposes continuous flow of invoices and eliminates queue time
Resource availability	13	36%	Invoices are waiting until looked at by individuals	Review responsibilities. Apply electronic system integrated to the outlook so individuals are notified by e-mail.
Control station	7	19%	Invoices are prioritized in the middle of the process in the way late invoices are pushed in system to be paid in the next check run while more recent invoices are delayed for another payment period.	Minimize invoice lead time and apply control station at the process end payment as per contractual pay term.
Average invoice waiting time (day)	22			

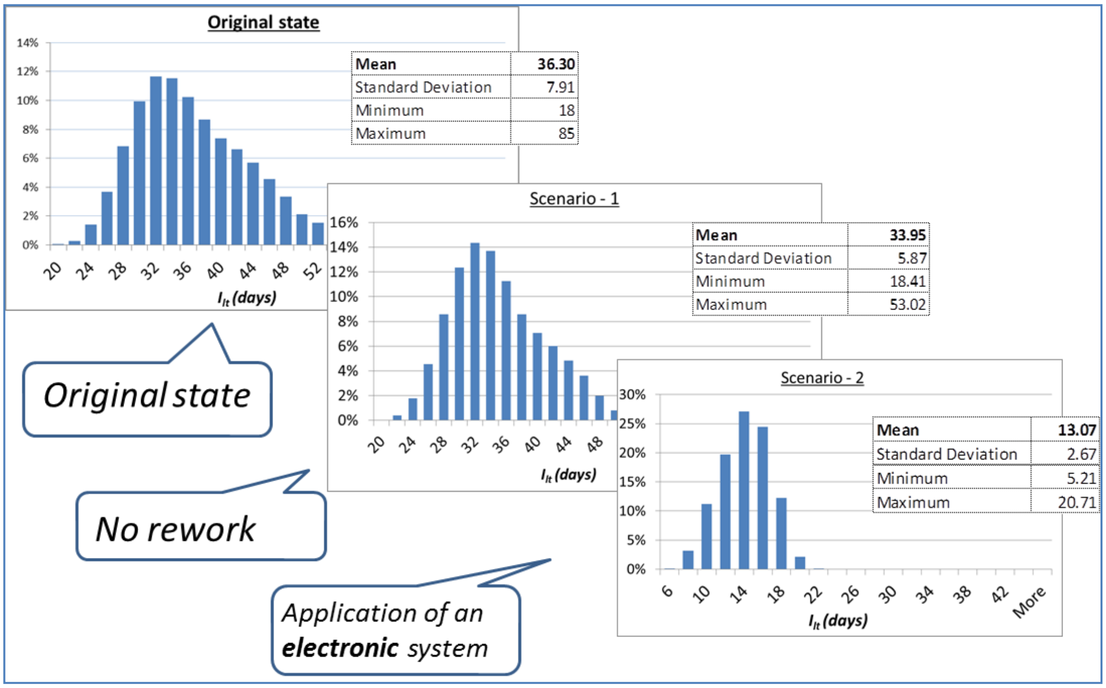

Figure 5-13. Simulation outcomes showing a decrease in I_{lt}

5.2 Invoice process improvement using cohort simulation (Markov chain)

To illustrate the methodology described above, a data collection protocol is employed in order to ensure that the transition probabilities provide a trustworthy description of the efficiency of the document processing chain. In this study, the speed at which documents are processed is not impacted by the number of invoices waiting to be processed. In other words, an employee does not adjust their speed based on the number of documents waiting to be processed, which in turn means that data can be collected during any month (season) of the year. The invoice processing chain of our industry partner, it should be noted, uses eight stations which are connected according to the process chart depicted in Figure 5-14.

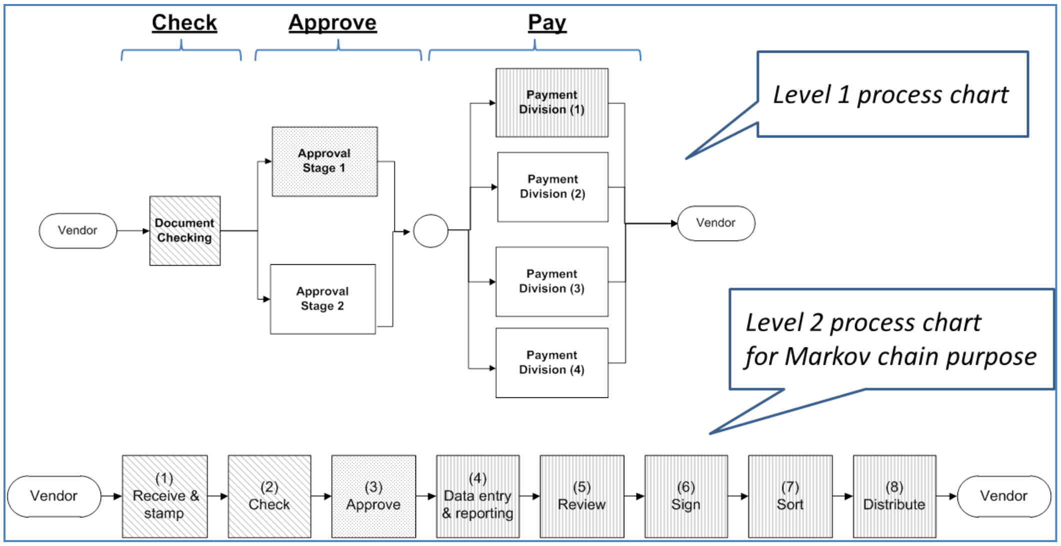

Figure 5-14. Invoice processing layout

In Figure 5-14, the invoice process is broken down into two levels. The Level 1 process chart consists of three phases—check, approve, and pay—while the "approve" phase is further divided into two stages and the "pay" phase is split into four divisions. According to the Level 1 process chart, a random invoice can follow eight possible scenarios (routes) from receiving to payment. One limitation of the Markov model is that it cannot model more than one route; therefore, this study suggests that (1) each route be modeled separately to calculate its lead time; (2) routes be ranked according to their criticality, where the longest lead time comes first; and (3) an improvement plan be developed considering this criticality. For this case study, the route shaded in grey in Level 1 was selected for Markov modeling, by which the invoice process was broken down into eight stations (Level 2). In order to evaluate the transition probabilities, data was collected at each station for 50 days randomly selected over a four-month period. At the end of each day, three numbers were recorded: (1) the number of received invoices, (2) the number of processed invoices (passed forward), and (3) the number of invoices which required rework (passed backward). These numbers are used to make daily estimations of the transition probabilities according to Equation (31),

$$s_{\text{current}\to\text{next,day=d}} = \frac{N_{current \to next, day=d}}{N_{day=d}},$$

and (31)

$$s_{\text{current}\to\text{previous,day=d}} = \frac{N_{current \to previous, day=d}}{N_{day=d}}$$

Where $N_{\text{day=d}}$ is the number of invoices received on day d at the station of interest. The probability for an invoice to remain at the same station can be calculated using the conservation principle, which leads to $s_{\text{current}\to\text{current,day=d}} = 1 - \left(s_{\text{current}\to\text{next,day=d}} + s_{\text{current}\to\text{previous,day=d}}\right)$. The elements of the transition matrix are obtained as the weighted average of the corresponding daily estimations satisfying Equation (32):

$$s_{i,j} = \frac{\sum_{d=1}^{\text{number of days}} \left(N_{\text{day=d}}\right)\left(s_{i,j,\text{day=d}}\right)}{\sum_{d=1}^{\text{number of days}} N_{\text{day=d}}} \tag{32}$$

Using Equation (32), the transition probabilities calculated for the nine stations which constitute the skeleton of the invoice processing system underlying this case study are summarized in Table 5-4.

Table 5-4: The transition matrix of the invoice process

		S1	S2	S3	S4	S5	S6	S7	S8	
Receive	S1	0.28	0.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Check	S2	0.04	0.46	0.49	0.00	0.00	0.00	0.00	0.00	0.00
Approve	S3	0.00	0.06	0.72	0.22	0.00	0.00	0.00	0.00	0.00
Data entry	S4	0.00	0.00	0.00	0.73	0.27	0.00	0.00	0.00	0.00
Review	S5	0.00	0.00	0.00	0.00	0.38	0.62	0.00	0.00	0.00
Sign	S6	0.00	0.00	0.00	0.00	0.00	0.65	0.35	0.00	0.00
Sort	S7	0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.64	0.00
Distribute	S8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.80
Station 9 (virtual)	S9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00

A state vector can be represented as $X_0 = (1,0,0,0,0,0,0,0,0)$, which represents a scenario of a single invoice fed to Station 1 (referred to as 0 elsewhere), the state vector describing the nine stations after n days of processing is expressed as $X_n = P^n\ X_0$. From a theoretical standpoint, reaching a state vector of the form

$X_{\text{final}} = (0,0,0,0,0,0,0,0,1)$ may take mathematically an infinite number of iterations depending on how quickly the process converges. However, in practice, one uses a tolerance factor (ε) which allows the iteration procedure to be stopped once the number of invoices at the last station (Station 9) satisfies the constraint: $n_{9,\text{final}} \geq 1-\varepsilon$. In this study, the researcher considers convergence to have been reached within $\varepsilon = 3\%$ (which reflects an estimation of the observed I_{lt}). Based on the values of the transition probabilities provided in Table 5-4 and the tolerance factor, we can now obtain a graphical representation of the invoice processing dynamics as documents move along the stations (Figure 5-15).

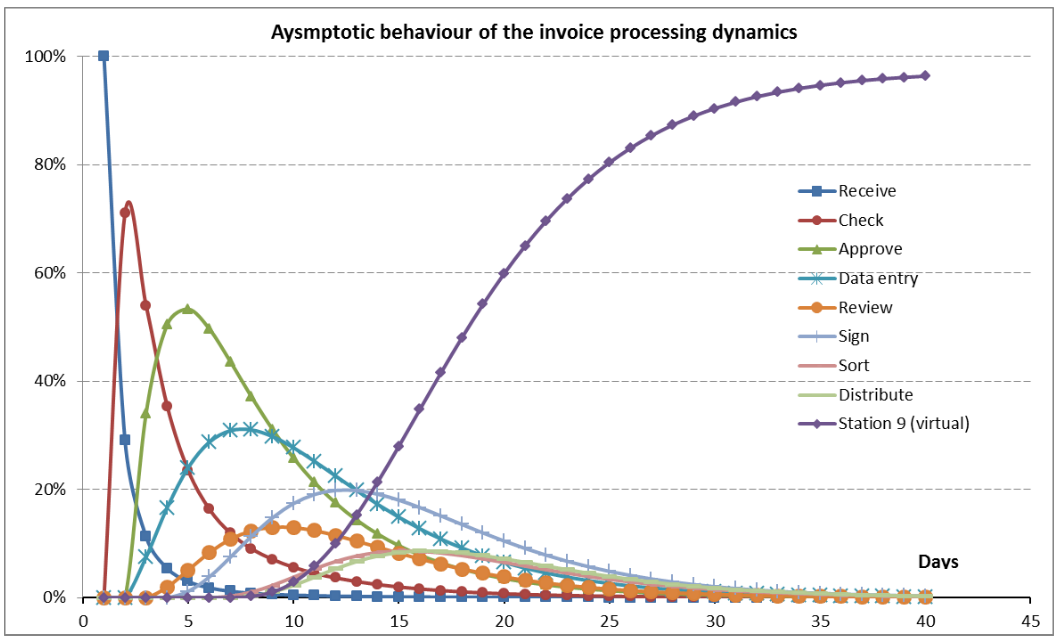

Figure 5-15. Invoice processing dynamics

The chart shown in Figure 5-15 provides important information to the process analyst, such as: (1) the I_{lt}, which is approximately 36 days from the virtual station line; (2) the I_{lt} per station (e.g., checking can take from 1 to 20 days); and (3) the bottleneck station(s) from the surface under the station dynamic profile. By applying Equation (15), the impact of each station relative to the overall process can be quantified, based upon which the improvement process can be prioritized. Table 5-5 presents the values of $B_{ref,j}$ calculated as per Equation (15) at each station compared to Station 1 as the station of reference. One can conclude that the main bottleneck is the "approve" station, followed by "data entry."

Table 5-5: Bottlenecks identified by calculating the surface under the station dynamic profile

Scenario	Station	Receive	Check	Approve	Enter data	Review	Sign	Sort	Distribute
Original	$B_{ref,j}$	1.0	4.8	8.4	6.8	3.0	5.3	2.9	2.3

Sensitivity analysis

In order to determine the impact of transition probabilities on the invoice lead time, which in the context of invoice processing is a metric for efficiency, the author addresses the sensitivity analysis from two different perspectives. To obtain some initial insight into fluctuations in lead-time, the bootstrap analysis method is applied (Cheng et al. 1996). It relies solely upon the collected data—50 records in the case of the present study. However, since for some stations invoices may be held for one or two days before they are processed, it was deemed reasonable to populate the transition matrix with the weekly percentages (an average of five records corresponding to five working days). The results of this analysis are summarized in Figure 5-16(a), in which a distribution is superimposed on the histogram following the bootstrap analysis.

Although bootstrap-based estimations can serve as a starting point to understanding I_{lt} distribution, it must be emphasized that the accuracy of such estimations might be limited, especially in the case of small datasets with large variances. Perhaps one of the most notable shortcomings of the bootstrap analysis is the narrowness of the range of the corresponding random variable, which essentially depends on the available data. In fact, this limitation is particularly pertinent in cases of small datasets for which the values are likely to be coming from the bulk of the distribution and thus are unable to provide any insight into the extreme regions further away from the bulk. The objective of using the best-fit method described in the above section is to solve these problems with the bootstrap technique. Thus, after fitting distributions to each of the transition probability datasets, random numbers representing the values of s_{ij}, see Equation (10), were drawn from these distributions and used to estimate the I_{lt}. The results of this experiment are provided in Figure 5-16(b).

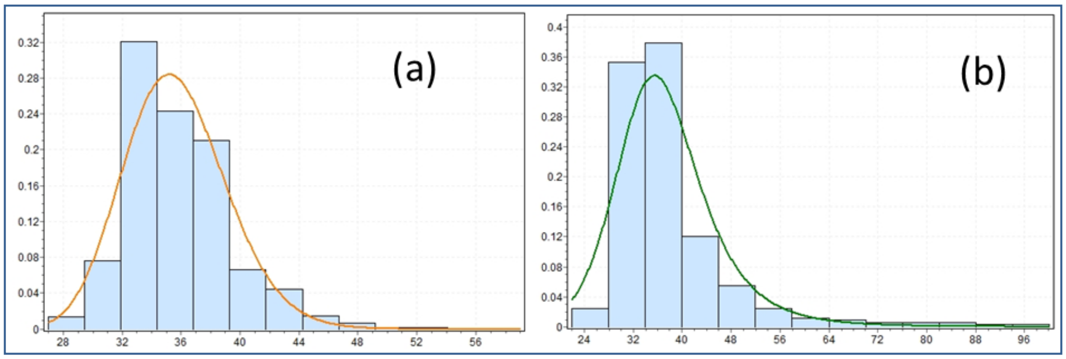

Figure 5-16: (a) Invoice lead time (I_{lt}) distribution calculated using the bootstrap analysis method; (b) Best-fit distributions-based simulation for invoice lead time (I_{lt})

Based on the above analyses, a legitimate concern that needs to be addressed is the determination, albeit qualitatively, of the accuracy of the above models. For the purpose of this comparison I_{lt} historical data were collected from the database of our industry partner; this dataset contained several hundred records spanning an entire year. For comparison of the methods, at the qualitative level at least, the histograms for the bootstrap model, the best-fit model, along with the historical data are shown in Figure 5-17(a).

According to Figure 5-17(a), there is a clear discrepancy between the bootstrap-based histogram and those obtained from historical data and the distribution best-fit technique. As mentioned above, the size of the dataset - which is used to build the bootstrap model, is crucial since a small dataset can be biased towards values corresponding to the bulk of the distribution. This is clearly seen in Figure 5-17(b), where the bootstrap histogram shows a strong bias towards values between 30 to 36 days, in addition to the absence of tail representation. However, the I_{lt} distribution built using historical data is in good agreement with that obtained from the distribution best-fit approach, even though the latter has a tendency to exaggerate the tail values slightly.

At this juncture it is worth noting the comparison between the logistic-normal model and the databased models—the distribution best fit and the bootstrap, respectively. It is important to emphasize that the logistic-normal approach is to be used as an approximation method, and is useful during the experimental design stage because it relies upon the knowledge (or, more precisely, educated guesses) about average transition probabilities. These estimates, easily obtained by interviewing the employees involved in the invoice processing chains, are used as inputs to the logistic-normal model (see Equations 12 to 14). The results of this analysis are summarized in Figure 5-17(b).

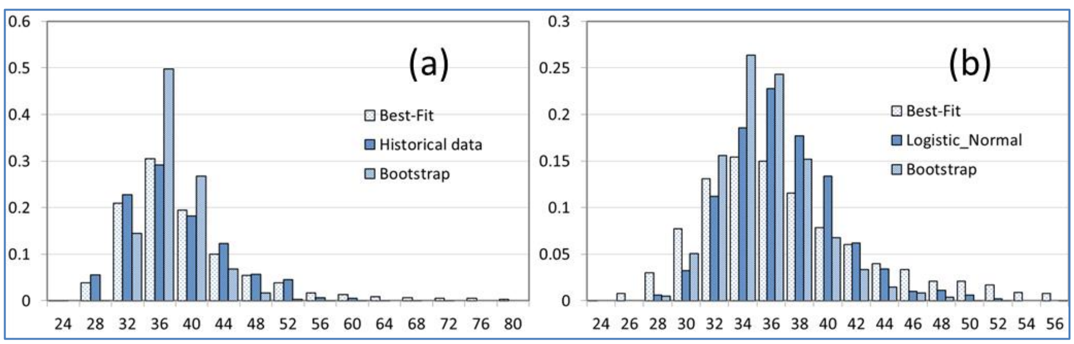

Figure 5-17 (a) Invoice lead time distribution from (i) distribution best-fit, (ii) historical data, and (iii) bootstrap; (b) Invoice lead time distributions as obtained using data-based models: (i) distribution best-fit, (ii) the logistic-normal design approximation, and (iii) bootstrap.

From Figure 5-17(b), it can be observed that while the logistic-normal model is not as accurate as the distribution best fit model, they are nonetheless qualitatively similar. More importantly, for this particular case study, it appears that the non-data-based logistic-normal approximation performs better than its bootstrap counterpart, which was constructed based on a rather limited dataset. These findings appear to support the qualitative adequacy of the logistic-normal model for quickly gaining insight into I_{lt} distribution.

In this study, any form of waiting time is considered waste. To identify waste, a focus group was selected from accounting, financial, and management personnel, and interviews and open table discussions were conducted to discover perceptions and exchange opinions about the invoice process. Discussions expanded to improvement suggestions, for which feedback was obtained and analyzed in terms of practicality. Table 5-6 demonstrates waste types for four stations, starting from the station with the highest $B_{ref,j}$ value calculated as per Equation (15). It also shows the associated root cause and the suggested improvement action.

Table 5-6: Waste identification in the current invoice processing system

Station	Waste	Root cause	Suggested improvement
Approve	Batch effect	Each invoice needs to wait until the batch is complete before it is processed.	Suggests changing to electronic invoice tracking system so invoice flow on FIFO (first in first out) bases.
	Rework	Technical or schedule related.	Revise vendor invoice requiremnets that includes clear instructions in order to increase accountability at the vendor level.
	Resource availability	Not a priority for the approver.	Change to electronic invoice tracking system that is connected to approver's
Data entry	Inconsistent document layout	Information is scattered in different locations within the invoice document.	Create a form (template) and ask contractors to change their invoice cover sheet accordingly.
	Sort prior to type in	Invoices need to be sorted by vendor name prior to entry.	Change to electronic invoice tracking system and move data entry upstream right after receiving station.
Sign	Resource availability	Not a priority to the signer.	Change to electronic invoice tracking system that is connected to approver's personal e-mail.
Check	Rework	The majority is related to variance between the contract and the invoice amount.	Revise vendor invoice requiremnets that includes clear instructions in order to increase accountability at the vendor level.
	Batch effect	Each invoice needs to wait until the batch is complete.	change to electronic invoice tracking system so invoice flow on FIFO (first in first out) bases.

The Markov model was utilized to assess the impact of improvement plans on I_{lt}. Two improvement scenarios were created for this reason: Scenario 1 eliminates rework and Scenario 2 applies an electronic invoice payment system in addition to removing rework. Figure 5-18 shows the decrease in I_{lt} from 36 days at a tolerance level of 3% to 33 days from the original scenario to Scenario 1, respectively.

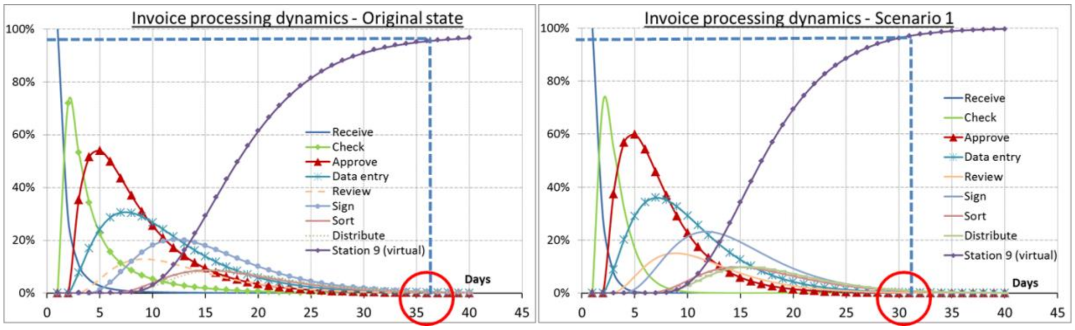

Figure 5-18. Invoice processing dynamics from original state to no-rework scenario

The I_{lt} decreases to 18 days when Scenario 2 is applied (Figure 5-19). This scenario assumes that the data entry task is moved upstream right after receiving with no held invoices ($s_{2,2}$ =0). It also assumes that 100% of the invoices in the "check" and "approve" stations will advance to the next station. The advantages of the electronic system extend beyond the reasons mentioned in Table 5-6 to include savings in storage space of archived hard copies and time savings if historical invoices need to be retrieved for claim or dispute purposes. The process itself needs to be reassessed after improvement actions have been implemented, until the targeted I_{lt} is achieved.

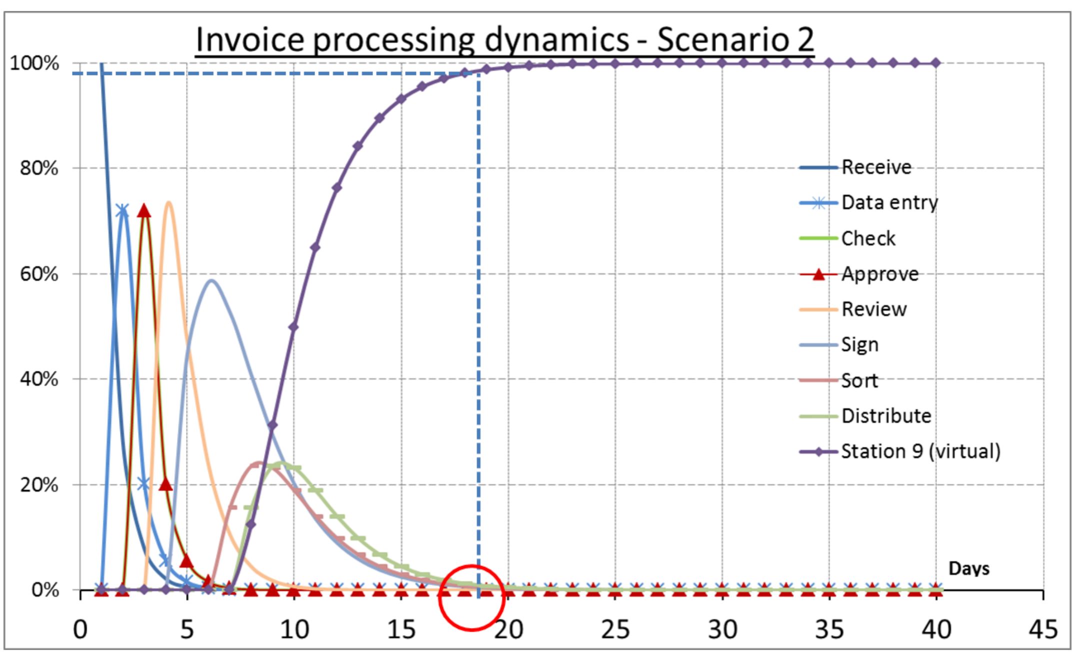

Figure 5-19. Invoice processing dynamics for Scenario 2

Findings from applying the two mentioned methods show that both can be applied to improve invoice process; however, there are cases where one method is preferred over the other. These cases are summarized in Table 5-7.

Table 5-7: DES versus Markov chain for improving invoice processing

Descrete Event Simulation (DES)	**Markov Chain**
When processing time needs to be improved.	Cannot track the improvement of processing time.
When the flow of invoices needs to be analyzed based on invoice charactaristcs (pay term, contract name, service type, etc.)	Since the transition probabilities are calculated as daily averages (invoices are not discriminated based on type or amount), this method cannot access the details of invoice processing.
Easier to model branches in the invoice process.	Cannot model more than one branch at a time. Invocie flow analysis has to be separate as well.
Needs more data and information to build the model. From the selected sample of invoices, data needs to be collected for every invoice at each station along the process.	Needs less data as a cohort of invoices is pushed into the system and data is collected for this cohort at each station.

5.3 A finance-based decision support model for homebuilders

The same homebuilder is considered as a case study for this approach. As a production homebuilder, the cash receipts are primarily bank progress draws, and disbursements include land- and job-related costs (direct costs), payrolls and company overheads. Table 5-8 below illustrates the major cash flow categories.

Compared to cash inflow that mostly comes from a single source and has a clear mechanism, the cash outflow is more complex. Thus in the first month, the initial focus was on investigating possible solutions for cash outflow forecasting, specifically the projection of construction PO expenses, which need to link the budgeting with the construction schedule, and also a clear understanding of the invoicing process and payment lead time.

Table 5-8: Major cash flow categories

Category			Forecasting method
Cash inflow (Receipts)	Bank progress draws		Forecast draws according to building schedule and the builder-bank agreement from the time the job is created by sale (sale agreement) to the possession date
Cash outflow (Disbursments)	Job-related cost	Land	Forecast payment according to lot procurement plan and developer-builder agreement
		Construction POs	Forecast POs' payments based on budget, building schedule, and invoice lag time
		Other costs	Forecast expenses (utilities, insurance, etc.) accoding to defined timeline
	Indirect cost	Payroll and benefits	Forecast expenses on division level based on HR/Accounting data
		Company G&A	Forecast expenses on division level based on HR/Accounting data

The company is in the process of developing a project control system that can track schedules, control costs, and reduce cash flow. The project control system includes two modules, cost and schedule. The cost module includes job estimates that are allocated to a Cost Breakdown Structure (CBS). The schedule module is used for tracking progress by job and it has its own work breakdown structure (WBS). No link exists between these two modules. POs are managed in a separate system (procurement system). Changes to the cost of POs are updated within the procurement system and do not feed the cost module to the project control system. The company uses financial software to facilitate paying invoices after approval. This software maintains historical data for invoices per job. There is also an internal network data (intranet) that maintains information and data related to the production plan as issued by business unit, the current inventory of lots and homes, and other information that is not related to this study. Based on the current state, two approaches (Figure 5-20) were first proposed to forecast the cash flow for this company: (1) build a statistical forecasting model based on historical data and, (2) build a cost-schedule integration model.

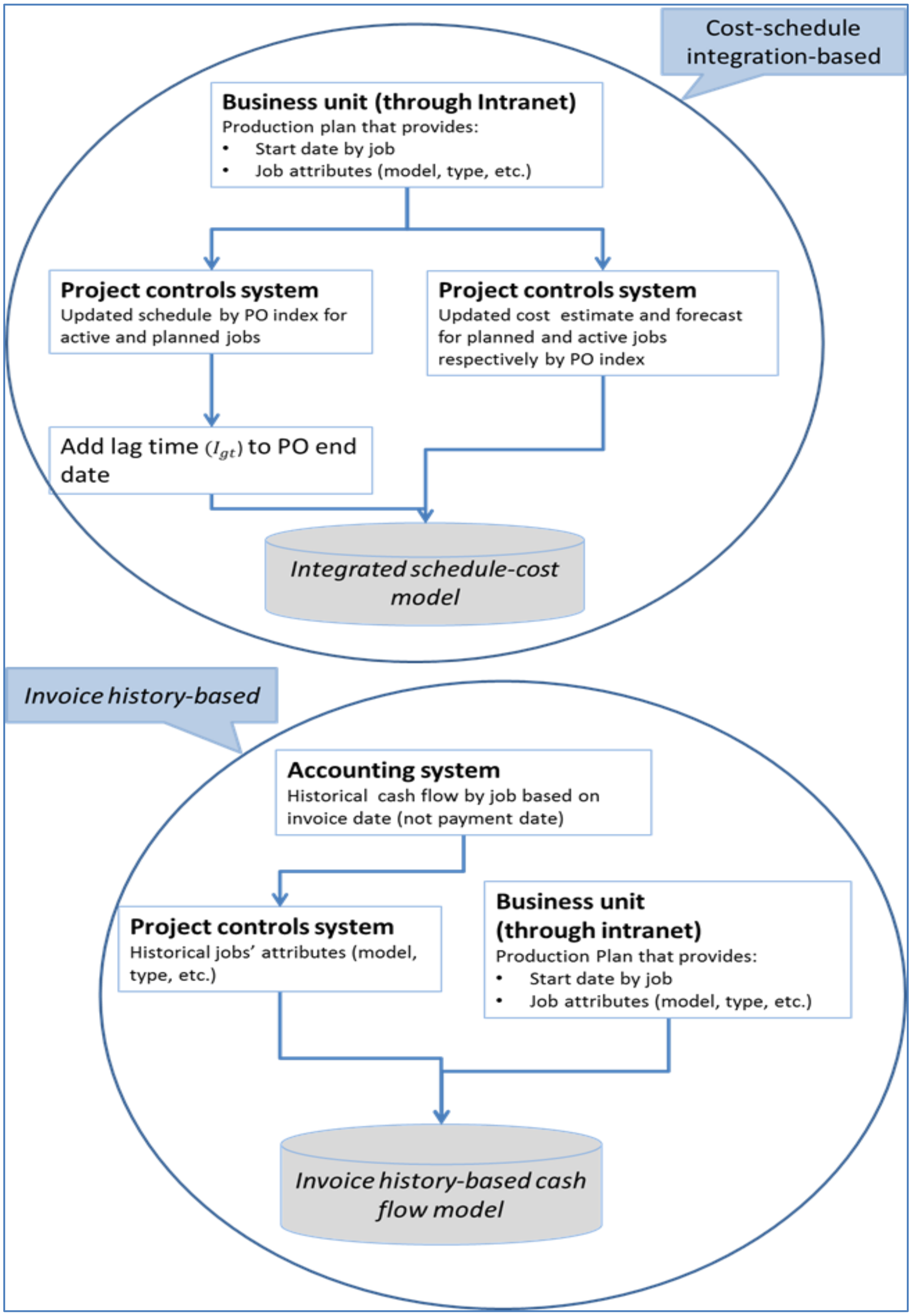

Figure 5-20. Cash flow prediction approach considering current information flow status in the company

Meetings were conducted with subject matter experts from the company to discuss the applicability of the proposed two scenarios. Based on the analysis of advantages and disadvantages of each approach (Table 5-9), and considering two criteria—system development and forecasting accuracy—the steering committee decided to adopt the cost-schedule integration approach.

Table 5-9: Cash flow forecasting approach: statistical versus cost-schedule integration model

	Advantages		*Disadvantages*	
Forecast method	**System development**	**Forecasting accuracy**	**System development**	**Forecasting accuracy**
Cost (PO) and schedule integration	Build as a separate module within the project control system.	Real PI data and updated budget provides better accuracy in the short term.	Need to match CBS and WBS at certain level for cost-schedule integration.	Subject to accuracy of in cost estimate and schedule
Invoice-based historical job payment curve	Can be a stand-alone system based on integrated intranet database and financial system.	Includes all job-related costs and construction delays.	Significant work on historical data analysis to formulate job payment curve of each house model and identify the impact factors.	1) Historical models don't reflect changes in market price, construction cycle time and process. 2) No historical record for new

The next step was to understand the company breakdown structure to identify the levels, of which required data and information can be obtained (See Figure 5-21). The cost-schedule integration level was selected at the contract (PO) level due to:

1. Most POs (over 90%) of invoices are submitted at the completion of the work specified in the contract.

2. Each contractor has a different billing time, that is, the time when work is completed to the time when the relevant invoice is received, and that leads to different invoice lag times.

3. Integrating cost and schedule on the lower level (activity level) is inefficient. It is time consuming from a system maintenance perspective and it will not add a significant value (increased accuracy) to the model.

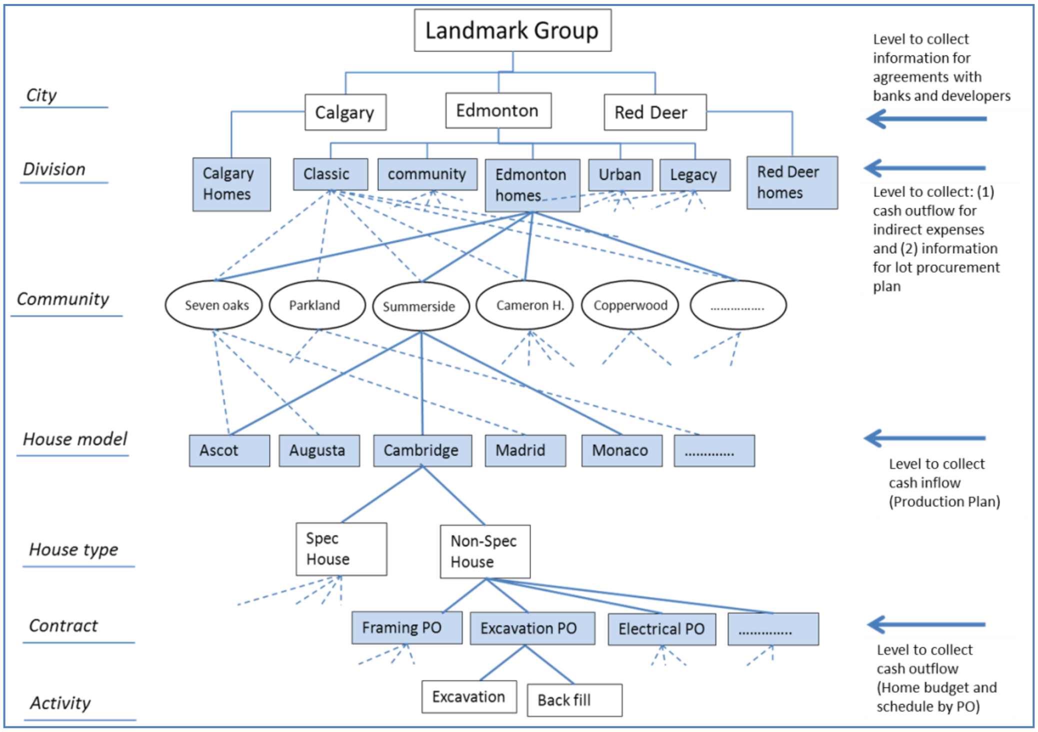

Figure 5-21: Cash flow forecast levels

The building phase consists of two stages: a pre-construction stage with an average duration of two months, and a construction stage with average duration of six months. POs consist of lump sum payments; once the scope of a PO is completed, one invoice is issued to be paid with a 40-day lag time, assuming 10 days for billing time and 30 days for lead time I_{lt}. Using templates in MS-Excel™ 2010, a prototype interface has been developed with the aim to predict the cash flow based on the equations developed above. The model includes an objective function and the constraints relevant to each of the proposed strategies. The interface consists of several interlinked templates described below (and depicted in Figure 5-22):

1. A production plan template for the next six months which includes home job number, predicted builder-owner contract date, construction start date allowing for a lag of 60 days for the pre-construction stage, and the estimated home price and cost (excluding lot cost).

2. A home schedule template that includes all homes listed in the production plan with a schedule broken down to PO level (construction activities), in which tasks are linked as per Equations 28 to 30.
3. A home budget template that includes all homes listed in the production plan with the budget broken down to PO level (construction activities). It also specifies the invoice lag time.
4. The bank agreement template, which list banks and their draw schedule as agreed with the builder. In this research, it is assumed that the builder deals with one bank only.
5. The developer agreement template that assigns the payment schedule to the developer as stated in the developer-builder contract.
6. The lot procurement plan that lists the predicted lots to be purchased and their prices, their expected developers, and the purchasing date.
7. The lot schedule template where the schedule of development milestones (DMSs) by lots are presented

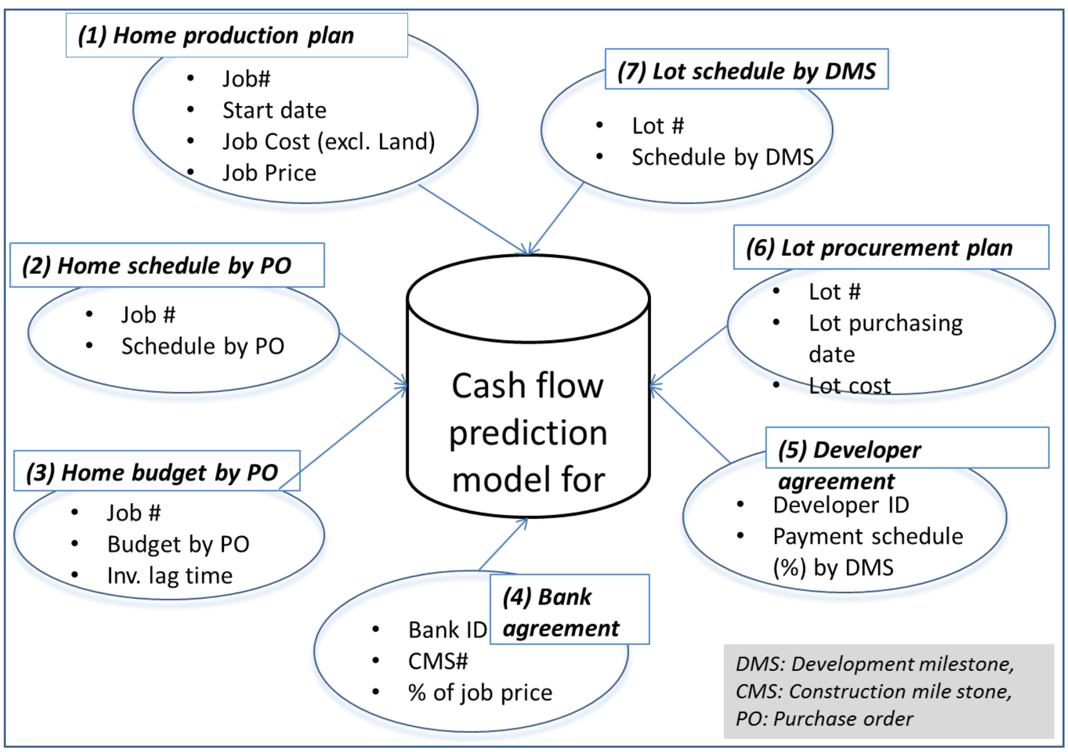

Figure 5-22: Cash flow prediction model for homebuilders

The objective of the optimization model is to minimize the negative cash flow (or maximize the cash flow), by changing either one of the invoice lead time, the production plan (homes' construction start dates), or the payment term in the developer-homebuilder agreement, as per Equation (33),

$$\begin{cases} \max\left(F_t\right) & t=1,2,\cdots,\mathrm{N} \\ \text{subject to} & \\ \min S_{p,1}^{CA} \le S_{p,1}^{CA} \le \max S_{p,1}^{CA} & \\ \min I_{lt} \le I_{lt} \le \max I_{lt} & \\ \sum_{i=1}^{u} p_{l,i}^{DM}\left(x_{l,i}^{DM}\right)=1 & i=1,2,\cdots,m \end{cases} \tag{33}$$

In which *N* is the number of banking transactions cycles within the cash flow time frame. $S_{p,1}^{CA}$ is the start date of the first construction activity (CA) in project p which affects successor activities as per Equations 28 to 30, I_{lt} is the invoice lead time which affects the invoice lag time as per Equation (26), and $p_{l,i}^{DM}$ represents the fraction (%) of the cost that needs to be paid to the land developer by day $x_{l,i}^{DM}$ after the home builder acquires the lot *l*.

Data was collected from a major homebuilder and scaled for the purpose of confidentiality. The model is run for each of these variables after defining the relevant constraints, and the resulting cash flow is analyzed to underline the most efficient strategy to achieve a preferable cash flow to homebuilder.

5.3.1 Finance-based production

The objective of the methodology is to explore alternatives (other cash flow management strategies) so the owner does not need to delay invoices to streamline the cash flow. This part of the cash flow model solution enables the manager to select the best production plan that fits the corporate financial capabilities by changing the construction start date (S_p) for project p considering the following constraints:

$$S_{p,1}^{CA} - 30 < S_{p,1}^{CA} < S_{p,1}^{CA} + 60 \tag{34}$$

$$\Delta S_{p,1}^{CA} = \text{integer} \tag{35}$$

Starting from the original state which has a 60-day gap between the sale agreement date and construction start date (pre-construction stage), the first constraint allows shifting the start date of construction 30 days ahead of schedule and 60 days behind schedule. The model user has the flexibility to loosen or tighten this constraint until achieving the desired goal. The user can also select a group of projects that allow for float more than others (e.g., apply it to speculation houses as no sale agreement is in place). Obviously the user needs to carry out a tradeoff analysis considering the financial cost due to longer inventory life and, in case of pre-sale projects, the relationship with the customer. Figure 5-23 shows the difference between the original (Scenario 0 - S0) and the optimized cash flow (Scenario 1 – S1) utilizing construction start dates for future projects in the cash flow time frame as variances.

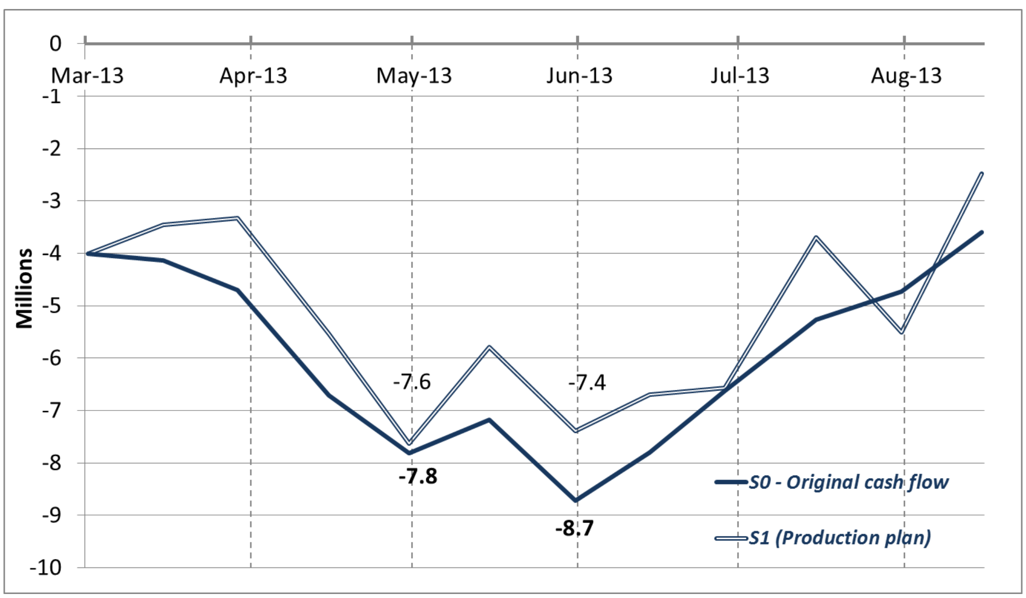

Figure 5-23. Impact of production plan variance on the cash flow

5.3.2 Finance-based payment

Most construction owners adapt delaying invoices to avoid short-term financial deficiency. This is done within, what is thought to be, limits that are acceptable to contractors. Although it is not preferable to delay invoices, in this section we examined the behaviour of cash flow if such an option is available in order to compare it with other scenarios (cash flow management strategies). Assume that invoices are paid within a lead time of 30 days and the acceptable limit of the invoice overdue time is 30 days, meaning an invoice can be paid within a range of 30 and 60 days. The following are the constraints that can be considered:

$$30 < I_{lt} < 60 \tag{36}$$

$$\Delta I_{lt_j} = \text{integer} \tag{37}$$

ΔI_{lt_j} is the change in invoice lead time for construction task (j). Solver does not allow for more than 200 variables, but the number of variables (invoices with lag time) in this example is 6,000. Therefore, 1,000 invoices of maximum values were selected as variables. These 1,000 invoices account for 56% of total invoice amounts of those scheduled for payment within the cash flow timeframe. Solver was run five times in sequence in order to change 1,000 invoices' lead times. Figure 5-24 shows the resulting cash flow due to the change in invoice lead-time from applying the constraints mentioned above. The cash flow was maximized to reach -$8.2 million by delaying 56% of invoice amounts up to 30 days. In order to reflect the impact of invoice delay, cash flow can be calculated using a more direct method such as Hendrickson's method (Hendrickson 1989); however, the approach described in the thesis was purposely chosen to provide a unified methodology and toolkit, namely MS Excel (Solver), which is the primary tool for other cases.

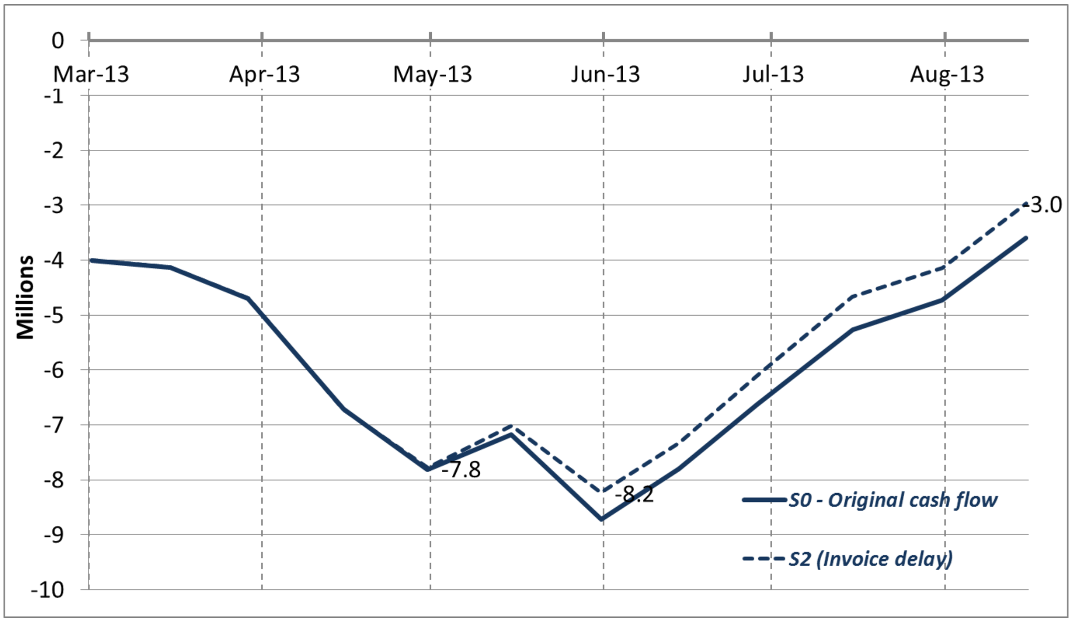

Figure 5-24: Impact of payment delay on cash flow

5.3.3 Finance-based payment schedule

Homebuilders need to purchase lots regularly to feed their production plan on time. Developers usually offer a piece of land that includes many lots. The homebuilder needs the resulting outflow from purchasing this number of lots to integrate smoothly with the existing ones, keeping the overall cash flow within desired limits. The proposed finance-based payment schedule recommends the optimal schedule for payment to be stated in the developer-homebuilder purchasing order, so that it best fits the homebuilder's existing cash flow with no (or minimum) harm on the developer. For simplicity's sake, the model assumes that developers have 10-month end milestones in general, from which a developer can select to assign payment as a percentage of the lot price $p_{v,i}^{DM}$. The following constraints need to be considered:

$$0 \leq p_{v,i}^{DM} \leq 1 \tag{38}$$

$$\sum_{i=1}^{10} p_{v,i}^{DM} = 1 \quad (39)$$

$$\Delta \, NPV_v = 0 \quad (40)$$

In which $p_{v,i}^{DM}$ is the ratio of lot cost associated with the development milestone (i) for developer (v). $\Delta \, NPV_v$ is the change in present value of the developer cash flow resulting from change of payment schedule. Figure 5-25 shows how the cash flow changes when selecting the best scenario for payment schedules. A better cash flow scenario could not be achieved, as the constraint of zero change in present value to the developer was a pending one. Therefore, the model was run again without this constraint resulting in cash flow shown in Figure 5-25. This run suggested paying the developer for part of the milestones in advance, thus leading to a positive present value for the developer ($76,700) and a loss of capital for the homebuilder ($39,300). Between the loss (to the homebuilder) and the resulting cash flow scenario, the homebuilder becomes better informed when negotiating pay terms with the developer.

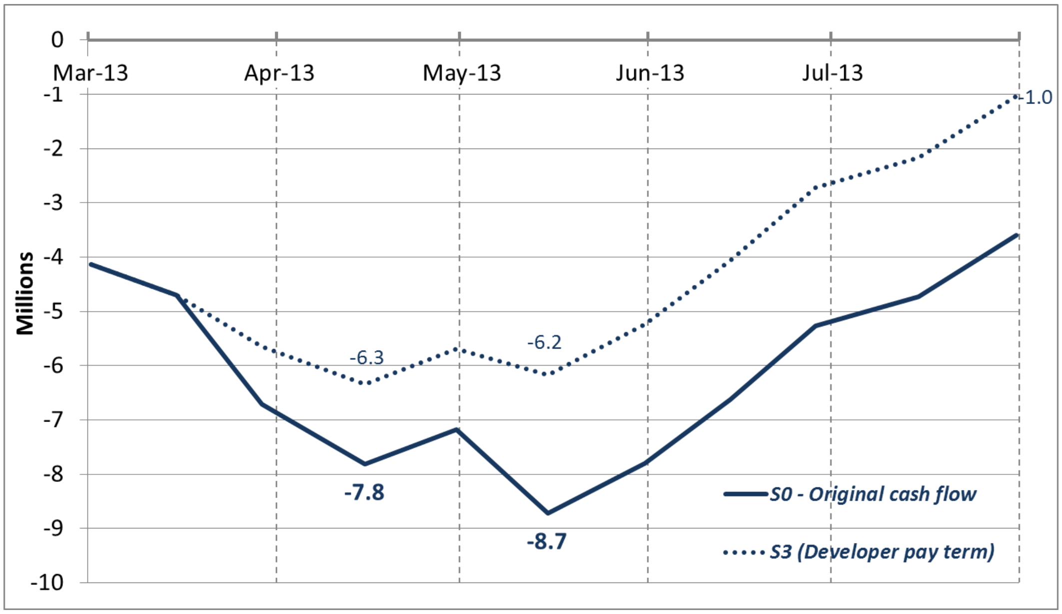

Figure 5-25. Impact of developer pay term on cash flow

The three cash flow management strategies—finance-based production plan, invoice payment, and developer payment schedule—are compared to each other in Figure 5-26. One can conclude that the finance-based developer payment schedule approach provides the best result. This conclusion cannot be generalized and it can be changed once the original cash flow changes (e.g., different production and/or land procurement plan); however, it emphasizes the advantages of exploring strategies other than delaying invoices to achieve a better cash flow.

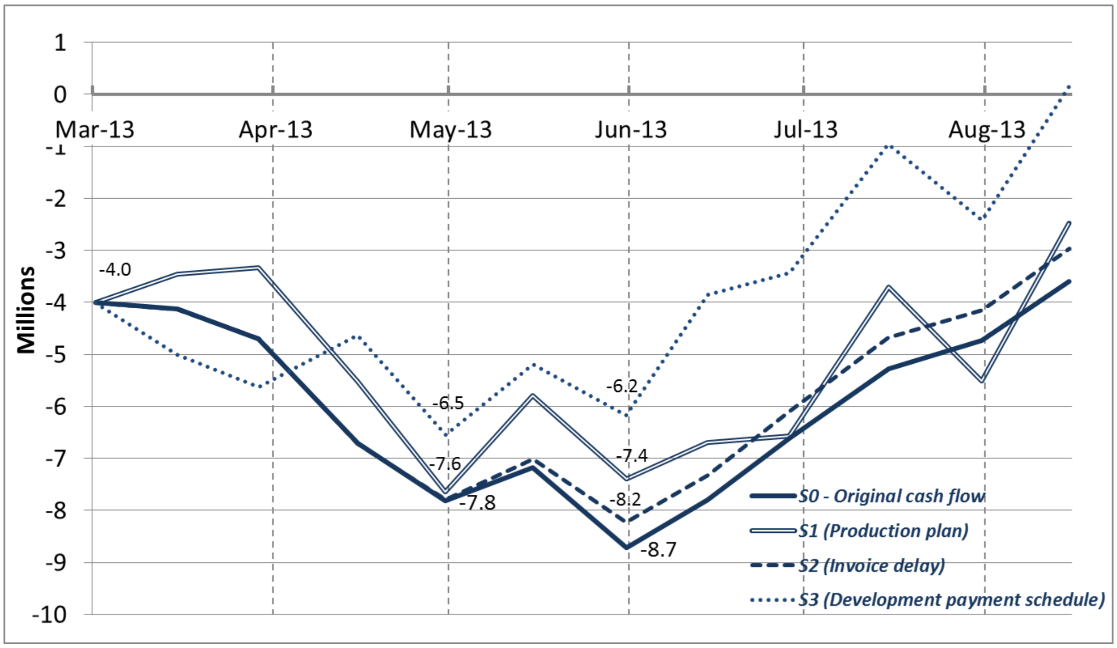

Figure 5-26. Comparison between the proposed cash flow management strategies

Chapter 6 - Conclusion and Recommendations for Future Research

The goal of this research is to minimize invoice delays in construction. This study has focused on three research questions: (1) what are the challenges pertaining to invoice payment, and how can their root causes be addressed? (2) How can these challenges be accommodated in a solution that satisfies stakeholders affected by invoice payment delay? (3) How can the proposed techniques within the resolution be integrated into the invoice payment system? This study has systematically identified challenges to invoice payment, considering the various contributing factors, and has provided a detailed insight into various techniques for reducing overdue invoice payments.

6.1 Research summary

The methodology presented in this thesis started with a motivation that laid down the reasons behind confronting the challenge of overdue invoices, a practice long-accepted by owners. The negative impact on owner, contractor, and subcontractor due to the volume of invoices circulating along with the extent of the overdue invoice problem was underlined. Then, methodologies of past researchers were explored, taking into account the parts affecting invoice-related aspects such as contracts and legislation, invoice processing, cash flow, and project financing. Dealing with an invoice as a product flowing along a production line, the literature review expanded beyond the overdue invoices to discover models that approached similar problems in nature (flowing product) in both manufacturing and non-manufacturing sectors. Methods to streamline processes similar to invoice processing were reviewed and studied, including lean manufacturing, discrete event simulation (DES), and cohort simulation (Markov chain). The literature review also uncovered the cash flow management aspect as another key reason why invoices are delayed. Accordingly, the study of past research included the strategies used to streamline cash flow in the construction industry and the methods proposed to efficiently utilize these strategies. This was followed by the background that explained the root causes behind the intricacy of invoice processing as complex contractual relationships in multi-project environments. The background also highlighted the reasons behind the challenge of cash flow prediction and management, including the project acquisition strategies as well as the uncertain nature of the predicted cash flow. The proposed methodology was based on the findings that invoice delay is mainly a consequence of either ineffective invoice processing or poor cash flow management. As a result, the proposed framework emphasized two approaches to solve the invoice delay problem in construction: (1) effective invoice processing; and (2) effective cash flow management. The methodology then illustrated the means and tools to achieve these two objectives within each approach in order to fulfill the main objective (minimizing invoice delay). The lean manufacturing techniques accompanied with discrete event or cohort simulations were adopted to achieve a streamlined invoice processing system. This was followed by an analysis of the simulation tools, addressing the advantages and disadvantages of each with regard to applicability and practicality. To address the problem from the project financing perspective, a financial decision model was developed to efficiently utilize cash flow management strategies, thus streamlining the cash flow and eliminating the need to delay invoices. The case studies were chosen to cover two main sectors in construction: heavy industrial and residential. The implementation of the proposed methodology followed the same track of the framework in which two approaches were presented. The data were collected for each of these approaches, the associated models were run, and the results were verified.

For the invoice process streamlining approach, two methods were proposed: (1) integrated lean and DES; (2) and Markov modeling (cohort simulation). A comparison between the two methods showed the advantages and disadvantages of each. During the research project with the collaboration companies, a list of challenges was identified and key lean strategies for overcoming those challenges were developed:

1) Long-term commitment of top management: This is crucial for the success of lean implementation. It includes allocating sufficient time and resources to assist in data collection, development of current and future state VSMs, and decision making for implementation.

2) Waiting time caused by process uncertainty: The key to eliminate or reduce waiting time is to maintain a consistent process along the stations, each of which produces invoices in an interval equal to the takt time. This method starts with establishing a pacemaker at the beginning of the invoice process. This pacemaker receives invoices at an inconsistent rate from various contractors and then feeds the invoices to the processing system at a steady pace equal to the takt time.

3) Waiting time caused by rework: The main reason for rework comes from the variety of invoices submitted by numerous contractors. Standardization is one of the main lean techniques that can confront this challenge. A contractor invoice requirement document should be established, which will standardize the invoice process among accounts payable business units, consequently causing less rework and redundant activities.

4) Processing invoices in batches: This is another way to accumulate waiting time. Fist-In-First-Out (FIFO) is a lean technique that can solve this problem. It can be implemented through an electronic invoice tracking system, which will allow invoices to move from one station to another electronically.

For the cash flow management approach, a financial decision model for homebuilders was developed that allows managers to find alternatives other than delaying invoices to avoid short-term financial tension. An evolutionary optimization was used to achieve this goal. The identified challenges along with proposed solutions are as follows:

1) The contractual relationships in homebuilding are complex. Different contracts rule the relationship between homebuilder and different banks, developers, and contractors. Each contract has it is own payment provision that includes a payment schedule and pay term. The developed cash flow prediction model integrated these payment provisions into the schedule and utilized them as decision variables in order to produce an optimal cash flow.

2) The Cost Breakdown Structure (CBS) and the Work Breakdown Structure (WBS) of projects (homes) were not aligned. Both structures were modified in order to align them on the PO level. This approach facilitated cost-schedule integration and created another decision variable from the invoice lag time.

6.2 Research contributions

Research targeting invoice delay has viewed the invoice payment from the processing perspective only. Researchers have applied lean manufacturing techniques to streamline the invoice processes on the contractor's side. Fewer researchers have undertaken this issue on the owner's side, and they have not expanded beyond the mentioned boundaries: the process. It is beneficial to both the construction owner and the contractor to establish a streamlined invoice processing approach that minimizes processing time and instances of overdue invoices. This exploratory research employed a combination of methods and tools to create a solution that can respond to this challenge from different perspectives. The major contributions of this research include:

1) A comprehensive framework that provides the owner with the necessary tools to minimize the invoice delay. The framework considers all aspects

contributing to this problem from two main perspectives, namely invoice processing and cash flow management.

2) An in-depth analysis of factors contributing to the long-accepted practice of invoice delaying. These include complex contractual relationships, ineffective legislation, inefficient invoice processing, poor cash flow management, and desire to maximize cash on hand.

3) The development of a flexible invoice processing improvement approach. Owners select the most suitable simulation tool in order to streamline their invoice processing.

4) The research employed two case studies reflecting most of the scenarios in the construction industry regarding invoice delay. Each of these case studies represents a major sector in construction reflecting differences in invoice volume, average invoice amount, payment provisions, and system in use (electronic or manual). The methodology developed in this research is, therefore, considered applicable to most construction companies.

6.3 Limitations

1) The developed cash flow prediction model for homebuilders is determinist; a stochastic model would better reflect the uncertain nature of the homebuilding business due to market, change in schedule and cost forecast, and inconsistent invoice lag time.

2) To simplify, the developed cash flow prediction model did not include the speculation type of houses. While this ads complexity to the model, it also provides flexibility to the cash flow manager as speculation houses have fewer constraints in comparison to pre-sold houses. They are not limited to a certain schedule, so their construction can be held, to a limit, at any stage until financial issues are resolved. The key constraint to these houses is the market (demand).

3) The financial decision model is developed for one homebuilder. Further validation of the proposed approach is left for future research in this area.

6.4 Recommendations for future study

The research undertaken in this dissertation demonstrates a successful approach for construction firms to pay invoices on time, but this approach is far from final and perfect. Based on the continuous improvement efforts of the case study companies, several areas of future research can be recommended:

1) The preliminary analysis of the invoice processing system can be expanded to address the impact of value on both invoice processing time and invoice lead time. This may lead to different scenarios in the proposed future (improved) state to accommodate such an impact.

2) The statistical analysis of the invoice processing time is based on hours spent only. It is recommended for future research that the resulting cost impact based on the hourly rate for employees processing the invoice be calculated. It is also recommended that the difference in hourly rate between one employee (e.g., account payable to manager) be calculated, such that the weight for the statistical analysis source of data can be better represented.

3) This study laid down the foundations to streamline the invoice process and verify through post-lean simulation. It ends at implementing the future map that reflects the proposed improvements based on lean concept. It is suggested that the research expand this methodology to develop a live diagnostic system, by which bottlenecks can be monitored automatically based on severity (invoices in queue relative to other stations) and frequency. This can be achieved by integrating the proposed tools (lean and simulation) into the electronic invoice system.

4) Other approaches to avoid delaying contractors' invoices can be examined such as:

   a. Applying advance payment provisions: This approach can be analyzed in respect to advantages and disadvantages to owners and contractors in order to achieve a win-win resolution.

   b. Rethinking the owner contracting strategy in which invoice volume can be reduced: For example, several POs can be combined in one for a contractor performing the same scope (e.g., plumbing) on different homes. Consequently, instead of multiple invoices, one invoice is issued where cost is broken down by home. The result is more visible on larger scale when this can be applied to several contractors, each of which may perform work for more than 10 homes at a time.

5) Although the sole objective for the financial decision model is streamlining the cash flow to fit the purpose of this study, researchers can add conflicting objectives such as minimum capital cost and minimum project duration. It is also suggested the market be considered as one of the main constraints affecting the main objective.

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