To Phase or Not to Phase: Quantifying the Effect of Phasing Construction Projects

Mikael Collan and Jyrki Savolainen
LUT University,
School of Business and Management, Lappeenranta, Finland

Abstract

Phasing construction projects is an interesting possibility that has received only limited attention in the academic literature, especially the quantification of benefits from phasing and the effect phasing has on project risk have not been fully explored. This paper presents two approaches to analyze the effects of phasing in the context of construction projects: a simple fuzzy logic-based method for preliminary analyses and a system dynamic simulation-approach for deeper analysis with timing. Both approaches are illustrated with a numerical example case. The presented results are new in academic literature and of practical relevance to managers and investors working with construction projects.

Keywords: Real Estate, Real Option, Risk Management, Pay-Off Method, System Dynamic Modeling

1. Introduction

Phasing, also known as staging, means splitting a large investment into smaller parts and investing stage by stage. Phasing typically limits the downside risk of uncertain investments, because it gives the investment owner the option to decide whether to continue, to wait and see, or to abandon the investment altogether after each investment stage. The decision to continue is typically made based on how well the previous stage of the investment has fared and on the forecasted future. An alternative to phasing investments is to make investments without phasing that is, to make a single-shot investment decision to fund a (potentially multi-phase) project completely at once. When an investment decision is made, it makes sense to find out before investment which one of the two investment strategies is better. This is something that is typically not always done and hence the issue is non-trivial, even if it would seem to be so. In many cases phasing an investment will change the expected profitability and the risk characteristics of the investment – when the profitability and the risk characteristics change for the better, phasing should be the way to go.

Phasing is a commonly used practice in the field of research and development, where uncertain investments are often split into phases (Herat & Park, 2007); (Pennings & Lint, 2000) (Brandao, Fernandes, & Dyer, 2018; Pennings & Sereno, 2011). Industrial and infrastructure investments with uncertain demand, or uncertain future prices, are also often built in phases (Ashuri, Lu, & Kashani, 2011; Cardin, Zhang, & Nuttall, 2017; Lawryshyn & Jaimungal, 2014). In this research we are interested in phasing within the context of *construction project investments* and more specifically in *quantifying the effect phasing has* on the expected value and the risk-profile of *individual* construction projects. The main question that we pose is: "how much is the possibility to phase a construction project worth?" and the logic we apply to answer this question can be simply formulated as:

$$[\text{Value of phasing}] = [\text{Project value with phasing}] - [\text{Project value without phasing}] \quad (1)$$

This is a well-known logic to study the value of *real options* in general. Real options are flexibility found in real-world investments, such as the option to phase the construction of a real estate investment that we are interested in here. There is a wide literature in place that discusses the theory and practice of real option analysis (ROA) and real option valuation (ROV) see, e.g., (Trigeorgis, 1995, 1996). But the literature on phasing in the context of real estate investments is rather scarce. Guma and others (Guma, 2008; Guma, Pearson, Wittels, de Neufville, & Geltner, 2009) point out that the valuation of phasing real estate development is a difficult problem from a modeling perspective, because the valuation situation is *context dependent* as the value of the construction investment and the possibility to phase depend on who is making the investment. This means that available information is also most often normative and a lot of the available information comes from experts. Guma and others also observe that the put-call parity does not hold for options to phase corporate real estate development.

We present how *two methods*, the pay-off method and system dynamic modeling with simulation, can be applied in the quantification of benefits from phasing. The pay-off method (Mikael Collan, Fullér, & Mézei, 2009) is a robust real option valuation method usable in situations, where limited and imprecise information are available and it is suitable for initial "quick and dirty" analyses also, when better information is available.

System dynamic modeling (Forrester, 1958, 1961) requires good knowledge of the problem structure and precise information about the uncertainties involved. When such information is available and a realistic system-model has been constructed, the results that can be generated through simulation can be quite precise and may also include information on optimal timing of actions. System dynamic modeling and simulation can be said to be a deeper form of analysis than what can be achieved with the pay-off method in this context. Figure 1 illustrates the positioning and the focus of this research with the two methods used.

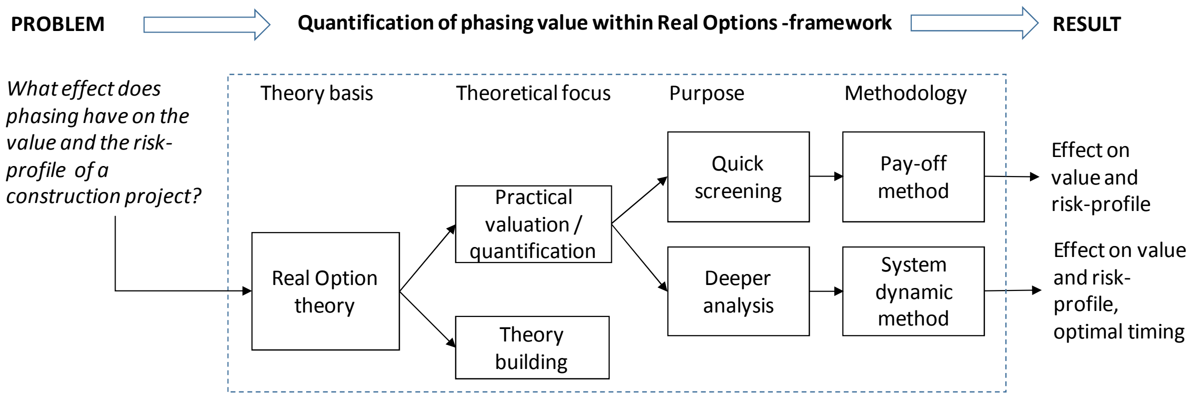

Fig 1. The positioning and focus of this research

The rest of this paper is structured as follows. The following Section 2 presents the results of a literature study on phasing in the context of real estate. Section 3 shortly presents the pay-off method and system dynamic simulation method Section 4 the numerical illustrations on how the effect of phasing can be quantified with the chosen two methods. Finally the paper is closed with a summary and conclusions are drawn.

2. Literature on the value of phasing in the context of real estate projects

To study the previous academic literature on the focus area of this research, we executed a literature search from the SCOPUS academic literature database until the year 2018, with the search string "phasing AND construction", which returned 395 documents and with the string “staging AND construction” that resulted in 967 documents. The searches were conducted on the title, abstract, and keywords. Of these hits only a handful are in any way relevant to the focus area of this research.

The relevant research articles discuss phasing in the context of construction technology, or the usability of facilities, while they are being renovated or extended, e.g., the effects of phasing to users or clients of public transport facilities under renewal (Fraser, Seel, Chadwick, Valambhia, & Offiler, 2012; Grigoryan, Jablonski, & Haase, 2015), the continuation of operations of ports, while they are being constructed (Jacob, Nye, McCollough, & Reid, 2004; McNeal & Miller, 2004), and hospital operations during renovation (Cox, 1986; DeMuth Jr., 1980). Berends and Dhillon (Berends & Dhillon, 2004). There are also a limited number of articles that discuss limiting construction cost-related risks by utilizing phasing (Couto & Ericson, 2017; Creaco, Franchini, & Walski, 2016; Knoles, 2016), these are all construction technology oriented.

To not leave out possibly relevant literature, a further search from SCOPUS until the year 2018, with the strings “staging AND option” and “phasing AND option” were made, where the subject areas were narrowed down to include “engineering”, “environmental science”, “social sciences”, “energy”, “economics, econometrics, and finance”, “business, management, and accounting”, “multidisciplinary”, “decision sciences”, and “undefined”. These returned 276 and 143 hits respectively. Scanning the results lead to finding five relevant articles that were not captured by the first searches.

Guma and others (Guma, et al., 2009) discuss vertical phasing of construction projects, in other words the possibility to allow for high rise construction projects to be phased. They illustrate the benefits of vertical phasing by using a number of real-world cases and make a strong case for the importance of considering phasing as an alternative, when decisions about construction investments are made.

Ott and others (Ott, Hughen, & Read, 2012) present a model for the analysis of phasing of residential housing development projects from the points of view of phasing development and of phasing the sales of the constructed of inventory. They observe that phasing decisions are important for the profitability of residential housing development projects, and that optimal production- (construction) strategies are expected to vary depending on specific factors surrounding each development project. Gemson and Annamalai (Gemson & Annamalai, 2015) discuss staging of infrastructure investments and focus on projects financed by private equity companies with over 350 real-world examples – although relevant, the article concentrates on financial risk management issues. Tang and Wang (Tang & Wang, 2017) discuss the effect of incomplete information on real estate development and show that under incomplete information phasing may speed real estate development. The above three articles all discuss the effect of phasing in aggregate terms.

The latest relevant article found in the literature search that discusses the effect of phasing from the point of view of an individual construction project is by Mintah and others from 2018 (Mintah, Higgins, Callanan, & Wakefield, 2018). The paper presents a case study to illustrate how the effects of staging in construction projects can be studied by using the pay-off method as a tool for quantification.

The literature study shows that the literature on phasing in the context of construction projects is not wide and there are only few instances, where practical quantification of the effects of phasing are analyzed.

3. Analysis methods used

Profitability analysis and valuation should be conducted with methods that fit the type of information available and the type of uncertainty that affects the project in question (M. Collan, Haahtela, & Kyläheiko, 2016). In the case of phasing real estate construction we assume that the type of uncertainty facing the decision makers is parametric (Kyläheiko, 1995; Langlois, 1984) and allows for the use of methods that require knowledge of the problem structure, while estimation of the parameter values is an issue of subjective beliefs, this is also backed up by the observations made by Guma and others (Guma, et al., 2009).

Investment analysis methods that are usable under parametric uncertainty include the most commonly used profitability analysis method, the net present value (NPV) method, many simulation based investment analysis methods, and fuzzy investment profitability analysis methods (M. Collan, et al., 2016). Because of the observed method-problem fit, the pay-off method and system dynamic model-based simulation are adopted as the methods to be used.

3.1. Pay-off method

The pay-off method (or the fuzzy pay-off method) (Mikael Collan, 2012; Mikael Collan, et al., 2009) is based on an idea of creating a net present value (NPV) distribution by combining information from multiple managerially generated cash-flow scenarios for which the NPV is calculated. The scenario-NPVs are used in the creation of a distribution that is called the *pay-off distribution* and that is treated as a fuzzy number. In this research we create and compare pay-off distributions for construction investments with and without phasing. In the construction of the pay-off distributions we refer to (Mikael Collan, et al., 2009) and observe that in this context the distribution construction will include the following steps:

i) we ask managers to provide three cash-flow scenarios "maximum possible" (everything goes as well as possible), "minimum possible" (everything goes as poorly as possible), and "best guess" (estimate of the most likely outcome) for both situations, when a construction investment is done as a single investment (all at once) and when the same investment is done in two stages
ii) we calculate the net present value for each of the three cash-flow scenarios by first discounting each cash-flow to present value and then by summing them up
iii) we observe that the best guess scenario NPV is the most likely one and assign it full membership in the set of possible NPV outcomes (*assign high point of the distribution*)
iv) we conclude that the "maximum possible" and the "minimum possible" scenario NPVs are the upper and lower bounds of the NPV distribution – higher or lower NPVs are not considered
v) we assume that the shape of the pay-off distributions is triangular (*when we use three scenarios we get a triangular shape distribution*) and that it is sufficient for the purposes of this (quick and dirty) evaluation.
vi) for any calculation purposes the created triangular NPV distributions are treated as fuzzy numbers

Triangular fuzzy numbers are defined as:

Definition 1. A fuzzy set set A is called triangular fuzzy number with peak (or center) a, left width $\alpha > 0$ and right width $\beta > 0$ if its membership function has the following form

$$A(x) = \begin{cases} 1 - \dfrac{a - x}{\alpha} \; if \; a - \alpha \leq x \leq a, \\ 1 - \dfrac{x - a}{\beta} \; if \; a \; \leq x \leq a + \beta, \\ 0 \; otherwise \end{cases}$$

and we use notation A=(a, α, β). For a more detailed illustration, please see for example (Mikael Collan, et al., 2009). Figure 2 shows a triangular fuzzy number, where point "a" represent the "best guess" NPV that has full membership in the set of possible NPVs and points "a- α" and "a+ β" represent the "minimum possible" and "maximum possible" NPVs respectively.

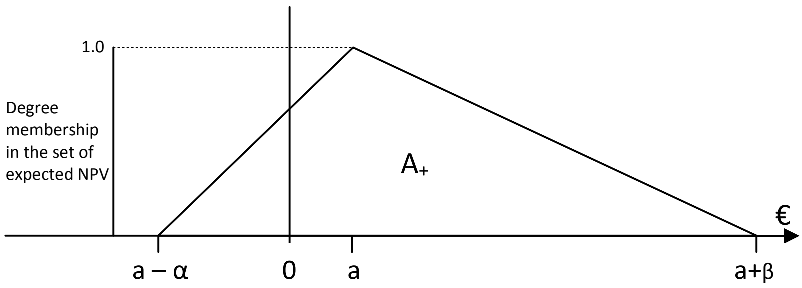

Fig 2. A triangular fuzzy number. Note: "α" is the distance between "a" and "a-α", and "β" the distance between a and "a+ β".

Constructing pay-off distributions for both non-staged and staged construction alternatives and calculating a set of descriptive numbers for both cases gives us intuitively understandable graphical and numerical information about the profitability outcomes of the two strategies and about the connected risk levels. The pay-off method has been also previously used in the analysis of construction investments, see (Mintah, et al., 2018; Vimpari, Kajander, & Junnila, 2014).

3.2. System dynamic model-based simulation

Model-based simulation is a method that is based on constructing a model that resembles the reality of the studied phenomenon, in this case the reality of a construction investment that is then used with simulation to study the effect different inputs into the model have on the outcome. As a result one is left with a distribution of possible outcomes from the model (and the phenomenon that it depicts) that includes also information about the frequency of different possible outcomes taking place. Typically the outcome is treated as a probability distribution of the outcomes. When a system dynamic (SD) (Forrester, 1958) model is used, one is able to take into consideration the internal interactions within the phenomenon, such as feedback loops, accumulation processes, and delays.

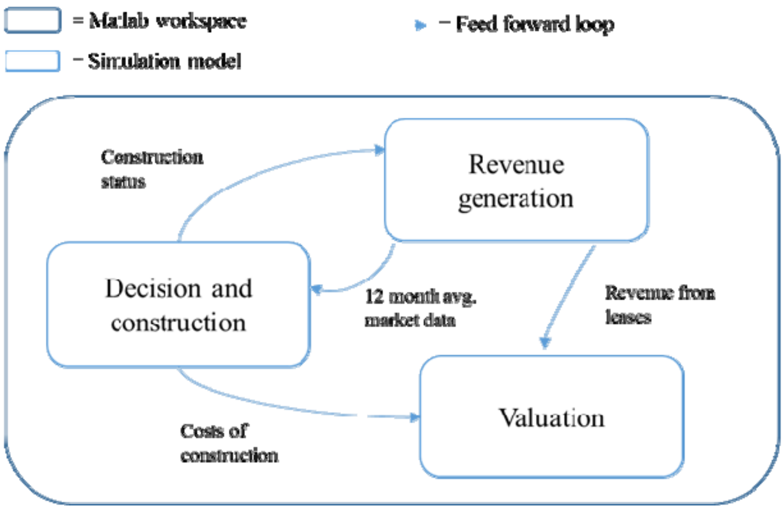

Fig 3. Blueprint of the SD-model used.

Simulations based on SD models have been used previously in many industries to analyze investments, examples include such fields as petroleum (Johnson et al., 2006), electricity production (Adetona, Salawu, & Okafor, 2013), and metals mining (O´Regan & Moles, 2001, 2006; Savolainen, Collan, & Luukka, 2016). This paper extends the use of SD models into the construction industry. The details of the SD model constructed for the purposes of this research can be found in Appendix 2 and a higher level blueprint of the model is visible in Figure 3.

The model used consists of three interconnected sub-models, “Decision and construction”, “Revenue generation”, and “Valuation” and has been built by using Matlab Simulink. The model can accommodate both, situations where the construction is done in phases, and when the construction is done all at once. Monte Carlo type pseudo-random simulations are run for both cases to value them. During a simulation run the SD-model changes its behavior on the basis of how the simulated uncertainties unfold. For example, if the simulated market conditions in the phased-investment case turn out to be positive, the model will trigger the start of the construction of the second phase automatically. If we can estimate future cash-flows reliably, then a system dynamic model

4. Numerical illustrations

Underlying the numerical illustrations we have a construction project case, where we assume that we are making an investment to a construction project with a “build and lease” business model of a 10000 m^2 office complex. We have to make a decision of whether to choose a strategy where we build the project at once, or a strategy, where we phase the construction project into two equally large 5000 m^2 construction phases. The total nominal construction costs are assumed to 15% higher in the two-phase construction strategy and that they are equally divided between the two phases.

We assume that the project has two sources of revenues, 70% of the rented spaces consist of long term leases and 30% of short term leases. The long term leases are assumed to be ten year contracts and to create a stable revenue with a low risk (of having unoccupied spaces and no revenue), while the short term leases are a minimum one year contracts that command a 10% higher rental income per square meter, but are more likely to cause empty periods between tenants. The rent is assumed to have a 3% annual growth (trend). In the quick and dirty analysis illustration we assume that the possible second phase will start in the beginning of year 5, no alternative starting times are considered. In the system dynamic simulation analysis we randomly draw the yearly used values for uncertain variables from triangular distributions constructed by using minimum, maximum, and best estimate values and use a mean reverting process to generate a yearly utilization rate for the spaces.

4.1. Illustration 1: Quick and dirty pay-off method analysis

The analysis with the pay-off method starts with eliciting cash-flow estimates and timing information for the project from experts in three scenarios for both, costs and revenues, and for both construction strategies. Based on practical experience, in addition to eliciting the best estimate cash-flows and timing information, we highlight the use of the terms "maximum possible (max)" and "minimum possible (min)" in eliciting the extreme scenario estimates, because they clearly convey information about the scenarios needed really being the extreme scenarios. The collected cash-flow information can be seen in Appendix 1.

It needs to be observed that in the maximum possible scenario the construction costs are counted according to the lowest possible costs and with the best possible realization schedule, and they coincide with the maximum possible rental income – the opposite applies for the minimum possible scenario. This is a so called min-max approach of constructing the cash-flow scenarios. Detailed information about how the cash-flows are modeled and about the construction schedules is presented in Appendix 2

After having the cash-flow and the timing information for the costs and the revenues, the present value for the cash-flows is calculated and summed up and the net present value for all three scenarios is calculated. NPV calculation requires the assessment of the costs' and revenues' risk levels for the derivation of proper discount rates. It is our position that separate discount rates for each different major cost and revenue factor should be used, because the risk levels are different, and using a single discount rate is not a necessary simplification. The different discount rates used here are a discount rate of 4% is used for the costs and a discount rate of 9% is used for revenues – these numbers are derived for the purposes of this example, but they underline the fact that the risks connected to costs (that managers can typically at least partially control) and to the revenues (controlled by markets) are different and that that difference should be reflected. The discounting is visible in Appendix 1. Separate and different discount rates could be used for the short term and the long term leases, and there could be a finer division of components inside the revenue and cost cash-flows used.

In the maximum possible scenarios we have assumed that there are no cost over-runs, or time table problems and thus the construction is finished according to the schedule and the revenues start to accrue faster than in the two other cases, where the construction is finished late. A visual presentation of the cumulative net present values for both construction strategies´ "profiles" are visualized in Figure 4.

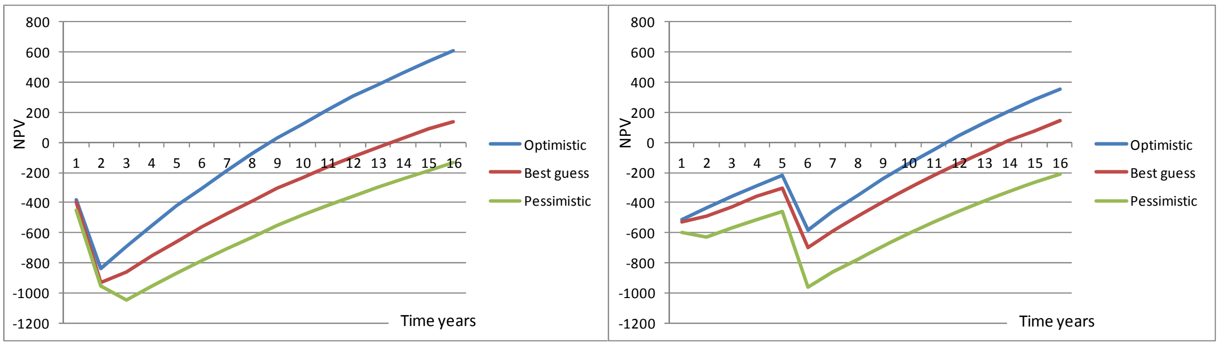

Fig 4. Cumulative NPV for the non-phased (left) and the phased (right) construction strategies

From the figure one can see how the present value cumulates differently in the three different scenarios and how the cumulated present value rises over zero profitability at different times. The time when the cumulative present value curve reaches zero profitability is the investment payback period in terms of present value. The distance between the three scenarios for the two strategies indicates the range of possible outcomes and is a proxy for risk. The visualization shows that the profiles of the two strategies are different in terms of how deep below zero profitability the alternatives dive at maximum, it is clear that phasing is a lower risk alternative from the point of maximum possible loss. In realistic circumstances it would be likely that one would not want to construct a second phase if the markets had evolved according to the minimum possible scenario, the cumulated cash-flows for this case are visible in Figure 5.

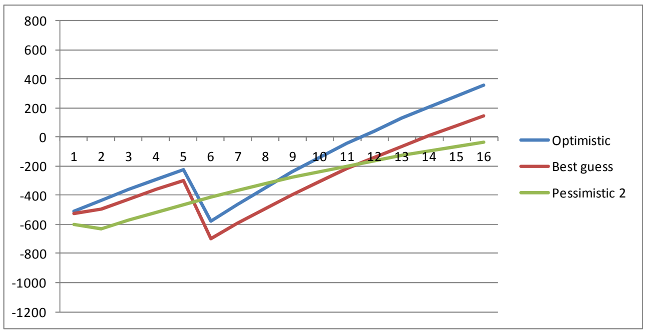

Fig 5. Cumulative NPV for the phasing strategy with no second phase built

When the NPV figures have been calculated for the three scenarios for both construction strategies the triangular pay-off distributions are created according to what is described above. The pay-off distributions for the two investment alternatives are visible in Figure 6. From the figure one can intuitively understand that the expected outcomes from the two-phase strategy are "lower" than those of the one phase strategy and that the expected outcomes from the two-phase strategy, where the second phase is not started they are more "tightly packed together" indicating a smaller variance in the expected outcomes. The minimum possible outcome for the two-phase strategy without starting the second phase is the least and indicates that in the worst case one is considerably better off with not going forward with the two-phase strategy. The maximum possible outcome of the one-phase strategy is clearly higher than that of the two-phase strategy however both are clearly positive.

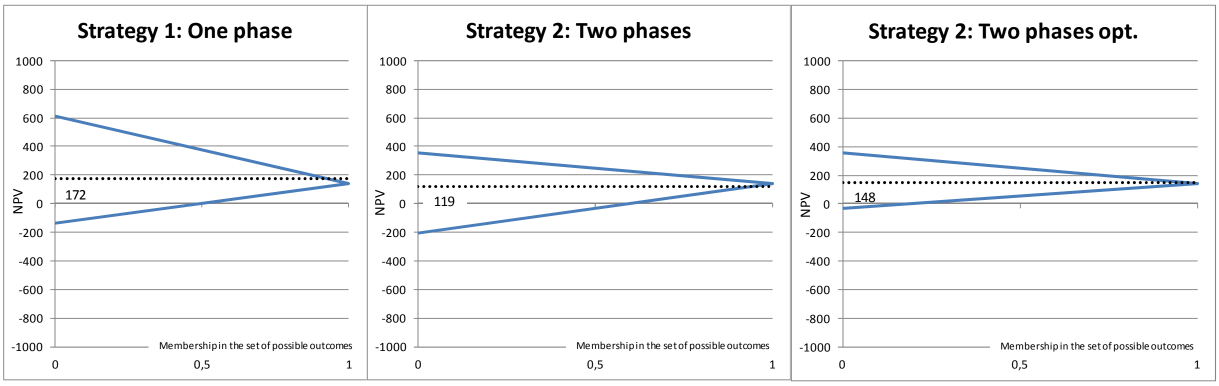

Fig 6. Pay-off distributions for the two investment strategies with the mean NPV (dashed line).

Descriptive numbers are calculated to further support the understanding of the differences between the two construction strategies. In addition to the three scenario NPVs we calculate the (possibilistic) mean NPV, a "risk factor", and a "success factor" for both strategies. The risk factor indicates how widely the possible NPV outcomes are distributed around the mean and formally it is the possibilistic standard deviation of the pay-off distribution. The risk factor can also be given as a percentage in relation to the mean. For the calculation of possibilistic mean and possibilistic variance we refer to (Carlsson & Fullér, 2001; Fullér & Majlender, 2003). The success factor is simply the percentage of the area of the pay-off distribution above the positive NPV outcomes, it is however not the same as the probability of a positive NPV outcome, one must remember that the pay-off distribution is a fuzzy number. The descriptive numbers are presented in Table 1.

Table 1. Descriptive numbers for the two strategies with absolute differences. Best of three underlined. Star indicates where one phase strategy is better.

	Strategy One phase	Strategy Two phases	Strategy Two phases 2	Difference One - Two	Difference One – Two 2
Optimistic NPV	<u>608</u>	355	355	253*	253*
Best estimate NPV	140	<u>142</u>	<u>142</u>	2	2
Pessimistic NPV	-136	-209	<u>-34</u>	73*	102
Mean NPV	<u>172</u>	119	148	53*	24*
"Risk factor"	152	115	<u>80</u>	37	72
"Risk factor, %"	88 %	97 %	<u>54%</u>	N/A	N/A
"Success factor"	91/100	78/100	<u>98/100</u>	13/100*	7/100

The difference between the value of two strategies is in essence the *value of phasing*. One can argue that the value of the phasing option is the difference between the mean NPV, or the best estimate NPV, of the project with the real option and without the real option, as observed in (1) above. In this case the real option to phase does not seem to be very valuable by these measures, but phasing seems to have an effect on the risk profile of the project and may be found fitting to the risk preferences of risk averse investors.

4.2 Illustration 2: Deeper analysis with system dynamic simulation model

Analysis with a system dynamic simulation model starts with the construction of the model. This is typically a time-consuming step that requires rather detailed knowledge about the problem structure and the dynamics within the problem, and the external "forces" that affect the problem as a function of time. The model used here is visible in Appendix 2 and consists of three sub-models that model the construction cost distribution and the decision-making with regards to the (two-phase) construction, the accrual of revenues from the project, and the profitability analysis (valuation) of the project.

Input variables into the model include revenues from the short- and the long-term leases and the timing of these, the construction cost and their timing, and a utilization rate that is a variable that governs the amount of empty spaces in the project and acts as a proxy to the real-estate rental markets. The time-step used in the simulations is one month. It is assumed that the construction costs are distributed evenly during the construction months (same construction time tables are used as in the pay-off method example, see Appendix 2).

In the simulation step of the analysis, the simulation randomly draws monthly values for the uncertain variables from triangular distributions that are defined by using minimum and the maximum estimated values as limits and best estimate values as the summit of the triangle, the values used are visible in Table 2. These values are used in generating the cash-flow table for the investment.

Table 2: Uncertain-variable value estimates used to create triangular distributions for simulation

Variable	**Unit**	**Pessimistic**	**Most Likely**	**Optimistic**
Initial leases (total)	*1000 /yr		168	
Increment	%/yr		3.0	
For one-phase investment				
Construction time	months	28	26	24
Construction cost	*1000	2 250	1 886	1 736
For two-phase investment				
Phase 1 constr. Time	months	14	13	12
Phase 1 constr. Cost	*1000	1 127	1 089	1 012
Phase 2 constr. time	months	13	12	11
Phase 2 constr. cost	*1000	1 130	977	919

To simulate market uncertainty, we introduce a time dependent variable called “utilization rate” the value of which is driven by a stochastic differential equation (SDE) that follows a mean reverting (MR) process for both the short (ST) and the long term (LT) leases. The mean reversion levels of the utilization rate are set as the as the assumptions in the pay-off method.???

NOTE!

WE have not been able to finish this part of the paper fully due to some unfortunate circumstances. We will submit a "better" version immediately, when we have the full corrections made (approximately 5th of February 2019)

Table 3: "Utilization rate" parameters; LT = long term, ST = short term

Market uncertainty (SDE)	Unit	Pessimistic	Most Likely	Optimistic
Utilization rate t = 0, LT	%	-	75,0	-
Utilization rate t = 0, ST	%	-	75,0	-
Utilization reversion level, LT	%	68	90	100,0
Utilization reversion level, ST	%	68	75	81
Volatility, LT	%	-	1,5	-
Volatility, ST	%	-	5,0	-
Mean reversion speed, LT	%	-	0,7	-
Mean reversion speed, ST	%	-	1,0	-

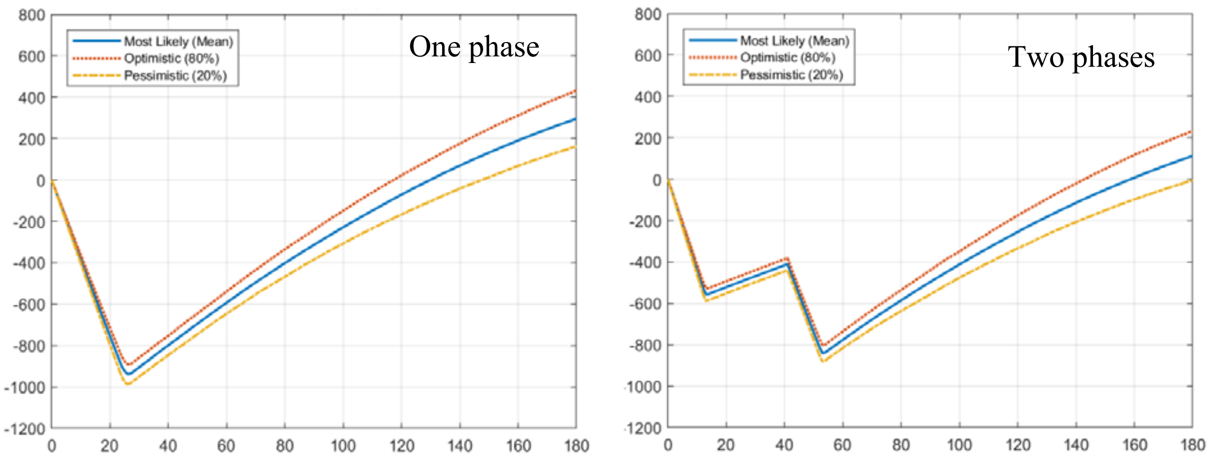

Fig 8. Cumulative NPV of the two strategies, means of 1000 simulations.

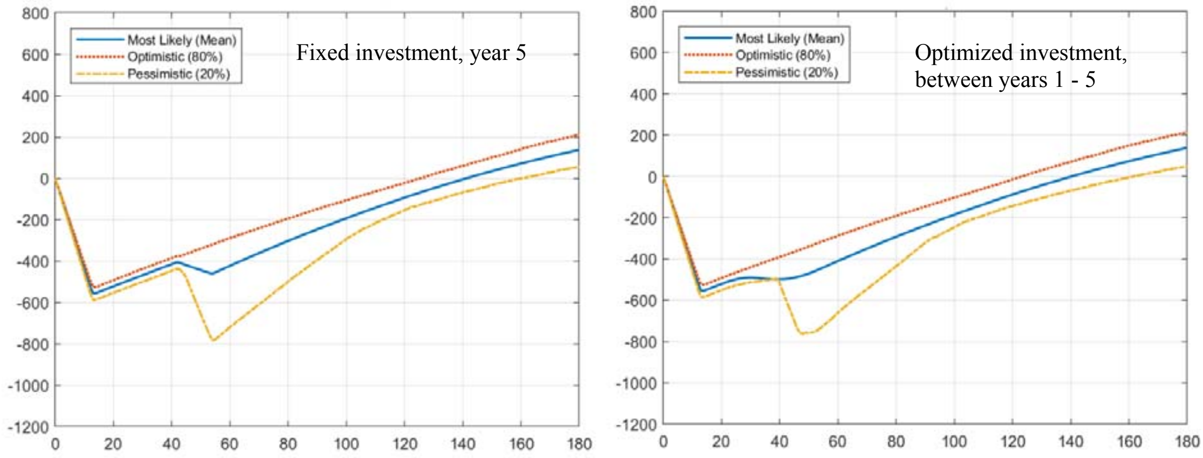

Fig 9. Cumulative NPV for the two-phase strategy, means of 1000 simulations.

Table 4. Comparison of simulated strategies corresponding to 1000 rounds of simulation. The numbers on **bold** are the best

Strategy	1-phase	2-phase	2-phase	2-phase
Timing	-	Fixed	Fixed	Variable
Trigger	-	-	Market	Market
Optimistic NPV	**432**	232	213	214
Best estimate NPV	**296**	113	138	139
Pessimistic NPV	**162**	-5.4	54.7	48.6
Positive NPV Mean	**307**	163	151	156
Success factor, %	**97.0**	78.8	93.3	93.1
Risk factor, %	**55**	126	81	134

5. Discussion and conclusions

This paper discusses the effect of phasing on the profitability and the risk associated with construction investments. In uncertain times considering phasing as an alternative construction strategy clearly makes sense, since it allows the investor to limit the investment downside. Although construction investments are very common a short literature review uncovered that the topic has not received a lot of attention in the academic literature.

In this research we have shown how the effect of phasing on the value and on the risk of construction investments can be analyzed. We chose two methods that serve different purposes in this context, the pay-off method usable in quick and dirty analysis and superficial exploratory analyses and system dynamic model-based simulation analysis usable for deeper analysis. The pay-off method has also previously been used in the context of analyzing construction investments and system dynamic model-based analysis has been previously used in many industries to study real options. The chosen methods have a good fit with the information typically available, when construction project investments are analyzed. The use of the chosen methods was illustrated with a construction investment case, for which strategies of constructing in one phase and in two phases were illustrated and compared.

The numerical illustration with the pay-off method shows that the method is suitable for the fast analysis of the effects of phasing on construction investments, when (a set of) second-phase starting times can be estimated. The results can be easily visualized, which makes them intuitively understandable. We have shown how the visual results can be supported with selected descriptive numbers that quantify different aspects of the alternative construction strategies to further support decision-making. By calculating the difference between the expected mean NPV of the alternative strategies, with and without phasing, a representative value for the real option to phase the investment can be calculated. It is shown that the pay-off method is simple and usable tool in the chosen context and we note that analyses with the method can be fully supported with the most commonly used spreadsheet software.

The numerical illustration with the system dynamic simulation model
PART ABOUT THE SIMULATION-BASED ANALYSIS IS MISSING AND WILL BE COMPLETED

Future research directions based and to continue on what is presented here include presenting real-world construction investment analysis cases to validate and enrich the models used, and to find out whether the models presented are usable also in practice according to construction company managers.

Reflecting on the above one can say that in the real-world setting, phasing construction is something that managers in the construction industry do intuitively. There are also other measures that managers do to mitigate the risk in construction investments, an example from Finland shows that construction of new commercial spaces is typically started only, when a considerable proportion of the leases of to-be-constructed spaces have been already been contracted. This is an indication of the fact that construction companies seem to be very risk averse and there is reason to believe that phasing is a highly relevant strategy for them to consider.

References

Adetona, S., Salawu, R., & Okafor, F. (2013). Simulink model for planning a new power transmission investment. *Simulation, 90*, 171-181.

Ashuri, B., Lu, J., & Kashani, H. (2011). A real options framework to evaluate investments in toll road projects delivered under the two-phase development strategy. *Built Environment Project and Asset Management, 1*, 14-31.

Berends, T. C., & Dhillon, J. S. (2004). An analysis of contract cost phasing on engineering and construction projects. *Engineering Economist, 49*, 327-337.

Brandao, L., Fernandes, G., & Dyer, J. (2018). Valuing multistage investment projects in the pharmaceutical industry. *European Journal of Operational Research, 271*, 720-732.

Cardin, M.-A., Zhang, S., & Nuttall, W. (2017). Strategic real option and flexibility analysis for nuclear power plants considering uncertainty in electricity demand and public acceptance. *Energy Economics, 64*, 226-237.

Carlsson, C., & Fullér, R. (2001). On possibilistic mean value and variance of fuzzy numbers. *Fuzzy Sets and Systems, 122*, 315-326.

Collan, M. (2012). *The Pay-Off Method: Re-Inventing Investment Analysis*. Charleston, NC, USA: CreateSpace Inc.

Collan, M., Fullér, R., & Mézei, J. (2009). Fuzzy pay-off method for real option valuation. *Journal of Applied Mathematics and Decision Systems, 2009*.

Collan, M., Haahtela, T., & Kyläheiko, K. (2016). On the usability of real option valuation model types under different types of uncertainty. *International Journal of Business Innovation and Research, 11*, 18-37.

Couto, R., & Ericson, D. (2017). A Case Study of Logan International Airport's Terminal C to e Connector: Structural Challenges and Risks for Existing Building Projects. In S. J.G. (Ed.), *Structures Congress 2017*. Denver, USA: American Society of Civil Engineers (ASCE).

Cox, J. C. (1986). Hospital renovation projects: phased construction requires planning at its best. *Hospital and health services administration, 31*, 114-125.

Creaco, E., Franchini, M., & Walski, T. M. (2016). Comparison of various phased approaches for the constrained minimum-cost design of water distribution networks. *Urban Water Journal, 13*, 270-283.

DeMuth Jr., W. J. (1980). Flexible phasing: a must for long-term construction projects. *Texas Hospitals, 36*, 18-20.

Forrester, J. (1958). Industrial dynamics - a major breakthrough for decision makers. *Harvard business review, 36*, 37-66.

Forrester, J. (1961). *Industrial Dynamics*. Cambridge, MA: MIT Press.

Fraser, J., Seel, D., Chadwick, J., Valambhia, K., & Offiler, A. (2012). Cannon Place, London: Design and construction over a live railway station. *Proceedings of the Institution of Civil Engineers: Civil Engineering, 165*, 74-81.

Fullér, R., & Majlender, P. (2003). On weighted possibilistic mean and variance of fuzzy numbers. *Fuzzy Sets and Systems, 136*, 363-374.

Gemson, J., & Annamalai, T. R. (2015). A new perspective on private equity stage financing: evidence from investments in infrastructure. *Venture Capital, 17*, 299-325.

Grigoryan, A., Jablonski, T., & Haase, D. (2015). New York City Grand Central subway station planned modifications and improvements. In M. C. Johnson & S. Oginski (Eds.), *2015 Rapid Excavation and Tunneling Conference* (pp. 18-28). New Orleans, USA: Society for Mining, Metallurgy and Exploration.

Guma, A. (2008). *A Real Options Analysis of a Vertically Expandable Real Estate Development.* Unpublished Masters Thesis, MIT, Cambridge, MA.

Guma, A., Pearson, J., Wittels, K., de Neufville, R., & Geltner, D. (2009). Vertical phasing as a corporate real estate strategy and development option. *Journal of corporate Real Estate, 11*, 144-157.

Herat, H., & Park, C. (2007). Multi-Stage capital investment opportunities as compound real-options. *The Engineering Economist, 47*, 1-27.

Jacob, A., Nye, L., McCollough, T., & Reid, T. (2004). Design considerations for phased construction of an operating container terminal. In S. A. Curtis (Ed.), *Port Development in the Changing World (PORTS 2004)* (pp. 229-235). Houston, TX., USA.

Knoles, W. (2016). Case Study: Using Value Analysis to Mitigate Airfield-Program Funding-Shortfall Risk. In *2016 Value Summit: The Power of VE*. Niagara Falls, Canada: SAVE International.

Kyläheiko, K. (1995). *Coping with technology: a study on economic methodology and strategic management of technology.* Lappeenranta University of Technology, Lappeenranta.

Langlois, R. N. (1984). Internal organization in a dynamic context. In M. Jussawalla & H. Ebenfield (Eds.), *Communication and information economics; new perspectives*. Amsterdam, Holland: Elsevier Science Ltd.

Lawryshyn, Y., & Jaimungal, S. (2014). Optimising a modular expansion of a wastewater treatment plant. *The Engineering Economist, 31*, 243-259.

McNeal, P. L., & Miller, M. D. (2004). The importance of construction phasing and flexibility at operating terminals -port newark container terminal case study. In S. A. Curtis (Ed.), *Port Development in the Changing World (PORTS 2004)* (pp. 1287-1296). Houston, TX., USA.

Mintah, K., Higgins, D., Callanan, J., & Wakefield, R. (2018). Staging option application to residential development: real options approach. *International Journal of Housing Markets and Analysis, 11*, 101-116.

O´Regan, B., & Moles, R. (2001). A system dynamics model of mining industry investment decisions within the context of environmental policy. *journal of environmental planning and management, 44*, 245-262.

O´Regan, B., & Moles, R. (2006). Using system dynamics to model the interaction between environmental and economic factors in the mining industry. *Journal of cleaner production, 14*, 689-707.

Ott, S., Hughen, W., & Read, D. (2012). Optimal Phasing and Inventory Decisions for Large-Scale Residential Development Projects. *Journal of Real Estate Finance and Economics, 45*, 888-918.

Pennings, E., & Lint, O. (2000). Market Entry, Phased Rollout or Abandonment? A Real Option Approach. *European Journal of Operational Research, 124*, 125-138.

Pennings, E., & Sereno, L. (2011). Evaluating pharmaceutical R&D under technical and economic uncertainty. *European Journal of Operational Research, 212*, 374-385.

Savolainen, J., Collan, M., & Luukka, P. (2016). Analyzing operational real options in metal mining investments with a system dynamic model. *The Engineering Economist, 62*, 54-72.

Tang, W., & Wang, Y. (2017). Incomplete information and real estate development strategy: Evidence from Hangzhou, China. *Habitat International, 63*, 1-10.

Trigeorgis, L. (1995). *Real Options in Capital Investments*. Westport, CT: Praeger Publishers.

Trigeorgis, L. (1996). *Real Options. Managerial Flexibility and Strategy in Resource Allocation*. Boston, Mass., U.S.: MIT Press.

Vimpari, J., Kajander, J., & Junnila, S. (2014). Valuing flexibility in a retrofit investment. *Journal of corporate Real Estate, 16*, 3-21.

Appendix 1: Cash-flow scenarios for building strategies 1 (no phasing) and 2 (with phasing)

Building Strategy 1: Build in one phase																
Time (t)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Cost Cashflows (in 100,000s)																
maximum	385	495														
best est.	400	550	50													
minimum	450	525	175													
PV of the cost					rd=	4,00 %										
maximum	385,00	475,96	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
best est.	400,00	528,85	46,23	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
minimum	450,00	504,81	161,80	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Revenue source 1: long term leases (in 100,000s)																
maximum	0,00	20,19	124,76	128,50	132,36	136,33	140,42	144,63	148,97	153,44	158,04	162,79	167,67	172,70	177,88	183,22
best est.	0,00	0,00	93,57	96,38	99,27	102,25	105,32	108,47	111,73	115,08	118,53	122,09	125,75	129,52	133,41	137,41
minimum	0,00	0,00	60,82	83,53	86,03	88,61	91,27	101,24	104,28	107,41	110,63	113,95	117,37	120,89	124,52	128,25
Revenue source 2: shorter term leases (in 100,000s)																
maximum	0,00	7,71	47,64	49,07	50,54	52,06	53,62	55,23	56,89	58,59	60,35	62,16	64,03	65,95	67,92	69,96
best est.	0,00	0,00	39,70	40,89	42,12	43,38	44,68	46,02	47,41	48,83	50,29	51,80	53,35	54,96	56,60	58,30
minimum	0,00	0,00	25,81	34,41	35,44	36,50	37,60	42,96	44,24	45,57	46,94	48,35	49,80	51,29	52,83	54,42
PV of the total positive wealth resulting from strategy 1					rd=	9,00 %	(it is possible to use separate discount rates for each revenue source)									
maximum	0,00	25,59	145,11	137,12	129,57	122,44	115,70	109,33	103,31	97,63	92,25	87,17	82,38	77,84	73,56	69,51
best est.	0,00	0,00	112,17	106,00	100,16	94,65	89,44	84,52	79,86	75,47	71,31	67,39	63,68	60,17	56,86	53,73
minimum	0,00	0,00	72,91	91,07	86,05	81,32	76,84	78,88	74,54	70,44	66,56	62,90	59,43	56,16	53,07	50,15
Net present value of Strategy 1: building in one phase										Mean NPV for strategy 1						
maximum	608									Mean NPV		172				
best est.	140															
minimum	-136															

Building Strategy 2: Build in two phases																
Time (t)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Cost Cashflows: phase 1 (in 100,000s)																
maximum	513,5															
best est.	526,25	27,5														
minimum	600	68,75														
Cost Cashflows: phase 2 (in 100,000s)																
maximum	0	0	0	0	0	513,5	0	0	0	0	0	0	0	0	0	0
best est.	0	0	0	0	0	553,75	0	0	0	0	0	0	0	0	0	0
minimum	0	0	0	0	0	668,75	0	0	0	0	0	0	0	0	0	0
minimum 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PV of the cost					rd=	4,00 %										
maximum	513,50	0,00	0,00	0,00	0,00	422,06	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
best est.	526,25	26,44	0,00	0,00	0,00	455,14	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
minimum	600,00	66,11	0,00	0,00	0,00	549,66	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
minimum 2	600,00	66,11	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Revenue source 1: long term leases (in 100,000s)																
maximum	0,00	60,56	62,38	64,25	66,18	68,17	140,42	144,63	148,97	153,44	158,04	162,79	167,67	172,70	177,88	183,22
best est.	0,00	45,42	56,14	57,83	59,56	61,35	126,38	130,17	134,07	138,10	142,24	146,51	150,90	155,43	160,09	164,90
minimum	0,00	28,26	49,90	51,40	52,94	54,53	112,34	115,71	119,18	122,75	126,44	130,23	134,14	138,16	142,30	146,57
minimum 2	0,00	28,26	49,90	51,40	52,94	54,53	56,17	57,85	59,59	61,38	63,22	65,11	67,07	69,08	71,15	73,29
Revenue source 2: shorter term leases (in 100,000s)																
maximum	0,00	25,70	26,47	27,26	28,08	28,92	59,58	61,37	63,21	65,10	67,06	69,07	71,14	73,27	75,47	77,74
best est.	0,00	19,27	23,82	24,54	25,27	26,03	53,62	55,23	56,89	58,59	60,35	62,16	64,03	65,95	67,92	69,96
minimum	0,00	11,99	21,17	21,81	22,46	23,14	47,66	49,09	50,57	52,08	53,64	55,25	56,91	58,62	60,38	62,19
minimum 2	0,00	11,99	21,17	21,81	22,46	23,14	23,83	24,55	25,28	26,04	26,82	27,63	28,46	29,31	30,19	31,09
PV of the total positive wealth resulting from strategy 1					rd=	9,00 %	(it is possible to use separate discount rates for each revenue source)									
maximum	0	79	75	71	67	63	119	113	106	101	95	90	85	80	76	72
best est.	0	59	67	64	60	57	107	101	96	91	86	81	76	72	68	64
minimum	0	37	60	57	53	50	95	90	85	80	76	72	68	64	61	57
minimum 2	0	37	60	57	53	50	48	45	43	40	38	36	34	32	30	29
Net present value of Strategy 2: building in two phases										Mean NPV for strategy 2						
maximum	355									Mean NPV			119			
best est.	142									Mean NPV with minimum2			148			
minimum	-209															
minimum 2	-34															

Appendix 2: Cash-flow calculation details

Pay-off method calculation details	**Strategy 1: One phase**	**Strategy 2: Two phases**
Size of the project in m^2	10000	5000+5000
Rent at year 0, per m^2	14,00	14,00
Rent multiplicator for short term lease	1,1	1,1
Increase of rent per year	3%	3%
Ratio of rented space long term / short term	70% / 30%	70% / 30%
Average empty space per year for short term leases	10%	10%
Maximum scenario average rented space of total	90%	100%
Best estimate scenario average rented space of total	75%	90%
Minimum scenario average rented space of total	y_0-y_6 65%; y_7-y_{15} 70%	80%
Total nominal cost of construction, index / absolute	100	115 (divided 50%/50%)
Maximum scenario 1st year of revenues / months of	Year 1 / 2 months	Year 1 / 12 months
Best estimate scenario 1st year of revenues / months of	Year 2 / 12 months	Year 1 / 10 months
Minimum scenario 1st year of revenues / months of	Year 2 / 9 months	Year 1 / 7 months
Second phase start year of revenues / months of	-	Year 6 / 12 months (all scenarios)

Appendix 3. Function block diagram of system dynamic simulation model created in Matlab Simulink®.