Bidding under uncertainty: Harsh Constructions

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Introduction

Vilas Birari had responded to many a "Request for proposal" (RFP) and had often converted such proposals or bids into construction contracts. However, in mid-August 2020, Birari – chairperson of Harsh Constructions Private Limited (HC) – was perplexed while preparing just such a proposal. The problem lay neither in the project specification nor in the demands of the prospective client. Instead, the problem lay in incorporating the uncertainty created by the COVID-19 (COVID) pandemic. COVID was a fast-spreading lung disease caused by an airborne virus (Zimmer, 2021). Declared as a global pandemic in March 2020, COVID had claimed one million lives globally by September 2020 (De Avila & Khan, 2020). Almost six months since the onset of the pandemic, not only had the health of millions suffered, but the ensuing lockdowns all over the world had caused economic havoc (Lahiri, 2020).

Within the construction business, Birari and others had experienced delays due to lockdowns, in the transportation of materials and availability of labor. Clients were not always willing to absorb the resulting budget and cost overshoots. Thus, it became even more important to embed a cost for dealing with the uncertainty into the proposal or bid itself. This created two further challenges – first, how much would be an adequate buffer to embed into the bid price to account for the uncertainty? And second, what if rival bids did not take the trouble to account for such challenges? HC could lose the contract if a rival came in with a "lowball" bid. So how should Birari balance the need to account for uncertainty with the competitive dynamics?

Background of Harsh Constructions Private Limited

Founded in the year 1990 by Birari, HC was based out of Nashik, the 24th largest city in India ("List of Cities in India by Population," 2022). While the Indian economy overall had grown at about 5% annualized between fiscal years 2016 and 2020, HC had experienced more than 60% annualized growth in revenues over the same period (Mallet, 2016; Suneja, 2020). From its humble beginnings as a contractor with two engineers and an annual turnover of INR 2m (US$26,817 [1]) in 1990, the company had grown to be a national player in the construction industry in India. In 2020, it had more than 500 full-time employees and an annual turnover exceeding INR 3.5bn (US$46.9m). See Table 1 for more detail.

HC's business scope included the construction of buildings for educational institutions, hospitals and industrial projects. In addition, under Birari's direction, HC had also begun to develop other infrastructure such as bridges and roads. HC had expanded out of its home state of Maharashtra into a few other large and prosperous, neighboring Indian states: Karnataka, Gujarat and Madhya Pradesh ("List of Indian states and Union Territories by GDP," 2022). Birari had aged well with the company: maintaining an affable and charming

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Table 1 Key financial indicators for HC

Financial indicators	*2017*	*2018*	*2019*
Revenues (INRm)	2,377	2,934	3,147
Revenues (US$m)[1]	31.87	39.34	42.20
Profit after tax (INRm)	140	176	202
Profit after tax (US$m)[1]	1.88	2.36	2.71
Profit margin	5.9%	6.0%	6.4%
Interest coverage (times)	6.8	6.8	6.2

Source: Created by the authors based on audited financials (Agarwal, 2020)

demeanour, especially when negotiating with clients. For day-to-day operational decisions, Birari had come to rely on Vikas Patil, the executive director. Patil was taller and leaner, with a more serious bearing than Birari.

Project specifications

In August of 2021, HC received an invitation to bid on a construction project for an academic institution – a leading Indian business school – in HC's home state of Maharashtra. The school – SP Jain Institute of Management and Research (SPJIMR) – is a private business school in Mumbai – the largest city and capital of Maharashtra ("Mumbai," 2022). SPJIMR is located on a 40-acre campus that houses another five higher educational institutions, all of which are part of a charitable trust called Bharatiya Vidya Bhavan. The parent trust runs 119 centres in India, 7 centres overseas and 367 constituent institutions overall ("Bharatiya Vidya Bhavan," 2022).

The project called for a proposal to build out a new student residence (also known as hostel building), and a multipurpose building. The multipurpose building was to house a student recreation area, a student cafeteria and a multi-storeyed faculty residence. The client had already appointed architects who had finalized a design for both of the buildings. SPJIMR had also specified an upper limit for the construction project: INR 1500m (US$20.1m). The client provided drawings and detailed specifications as part of the RFP process. The maximum permissible time to complete the project was 24 months, beyond which the client would exact a penalty of INR 5m (US$67,042) per month of delay. The deadline for submitting the proposal was the 30 September 2020, after which SPJIMR would review and select a single bid as the winner. Birari approached this call for proposal with enthusiasm, as HC had executed a similar project for SPJIMR in the past: a hostel building right next to the proposed new project.

Sources of uncertainty

Having been part of several other competitive bids in the past, Birari was familiar with some of the sources of uncertainty. As he shared with his senior team:

> We need details on how rivals might bid, and an analysis of the risks of the project. We need to know at what bid points the project still looks viable. Bidding too low could reduce margins to the point of incurring losses, and bidding too high could increase the chances of losing the bid altogether.

The strategic nature of the client, which was part of a much larger parent, motivated Birari to have his team put together a compelling proposal. However, Birari's enthusiasm was tempered by a major concern – the intermittent lockdowns that had become a constant pain during 2020 (Livemint, 2020). The Government of Maharashtra, like many other states in India, had declared a lockdown effective from 17 March 2020, which had led to shortages in labor, materials and other services (Pathak & Khanna, 2020). Since then, restrictions were partially lifted and then intermittently re-imposed as the infection rates spiked (Kumar, 2020). The above situation implied two effects: a likely rise in project costs due to shortages, and supply chain delays, which could result in overshooting project timelines. This latter effect increased the risk of incurring penalties due to delays in project completion. The challenge was to integrate all the sources of uncertainty into one bid. Birari knew that first, the team needed to collate data to evaluate the above risks.

Progress review

Birari called for a meeting in mid-August 2020 to review the state of data collection and analysis. The meeting began with Patil, the executive director, striking a cautionary note:

> Costs will remain very uncertain. Because of possible disruptions in transportation, we may have to get major items like steel and MEP (Mechanical, Electrical, Plumbing) from local vendors at higher prices. Also, due to the reverse migration of workers due to the lockdown, our regular workforce from Nashik (about 167 km distant from Mumbai) may not be available. So, we shall have to depend on local workers – at a higher cost.

At this point, Patil asked the head of the engineering team to share cost estimates for the project, taking into account the risk of budget and schedule overruns. The director of the engineering team, Moreshwar Behere, prefaced the team's presentation by noting: "This data is important as the pandemic has introduced new uncertainties and any delay shall attract monetary penalties." Behere's presentation focused on two tables: The first table (Table 2) estimated the likelihood of HC finishing on time. The table incorporated likely delays due to the ongoing uncertainty.

The second table (Table 3) provided an estimate of project costs under various cost headings, along with best- and worst-case estimates. This table, too, incorporated revised expectations due to the uncertainties of the COVID pandemic.

Table 2 Project duration estimates with associated probabilities of occurrence

Project duration scenarios (months)	*Probability of occurrence*
19	0.10
20	0.20
21	0.25
22	0.20
23	0.15
24	0.05
25	0.03
26	0.02

Source: Disguised company information courtesy HC

Table 3 Project cost report from the HC engineering team

Cost categories	*Expected*	*Minimum*	*Maximum*	*Standard deviation*
Civil work and construction (INR)	800	680	950	50
Civil work and construction (US$)	10.73	9.12	12.74	0.67
MEP (INR)	300	220	400	30
MEP (US$)	4.02	2.95	5.36	0.40
Total (INR)	1100	900	1350	60
Total (US$)	14.75	12.07	18.10	0.81
Project duration (months)	20	18	27	3

Notes: All figures in millions, unless otherwise stated
Source: Disguised company information courtesy HC

Behere reminded everyone that HC would incur a one-time, fixed cost of INR 5m (US$67,042) to develop a rigorous and compelling proposal. The proposal development process would include a professional survey of the site, analysis of the architectural plans, a preliminary project plan that would include phase-level schedules, milestones and costing, as well as compiling all of the above data and analysis in a coherent bid. Birari agreed: "Before committing to participation in this bid, we absolutely must assess the likelihood of making a profit on the project."

He agreed that the tables presented by engineering would help in developing a rough sense of cost-based pricing. But as Birari pointed out, this alone was not enough.

> I understand the invitation for bidding has gone to three or four other builders, and if our price is not competitive, we will not get the order. Can I now request our business development team to share whatever competitive intelligence they have managed to gather?

The business development team, led by Mr. Ranjan Mohapatra, had identified the likely contenders for the contract and had put together a thumbnail profile of each competitor. Based on recent responses to RFPs of similar scale, the team had identified three likely bidders: SPP, Reliable and PSL. All three competitors had a number of ongoing projects, and all were slightly larger in scale of operations than HC. Of these, SPP and Reliable were unlikely to bid as low as HC. As Reliable was headquartered outside the client's home state of Maharashtra, it was likely to incur higher costs, which would need to be covered by a higher bid. In recent bidding on other contracts, both SPP and Reliable had tended to bid higher than HC; driven by a lower risk appetite and desire for higher profitability, Mohapatra believed.

PSL was more risk tolerant and was likely to bid lower than the other two. Both PSL and SPP were based out of Maharashtra and had bid on several other medium-sized projects in the state. Finally, all three competitors tended to be more vertically integrated than HC, which outsourced more of the project to sub-contractors. Given the pandemic, all of the bidders were likely to pass off some of the project risk to their sub-contractors. Mohapatra also mentioned that large national builders such as Larsen & Toubro and Shapoorji Pallonji Group were unlikely to participate in the bidding for the SPJIMR project. Such builders maintained a portfolio of mega projects, and the scale of such a project was too small to be a good fit for their portfolio.

Mohapatra presented the team's findings (Table 4) on the range of bid prices and associated probabilities for the most likely contenders. He began with a caveat: "Please note that the data is our best estimate only. We believe it is accurate within a certain range, but given the current uncertainty, we should not be surprised if there is some deviation."

Mohapatra ended his presentation on a positive note:

> Since the tenders have gone only to reputed parties with a proven track record, the lowest bidder is likely to get the order. But in case of a tie, HC is likely to get the order since we have already done a project for SPJIMR and they have expressed their satisfaction.

Table 4 Competitive intelligence report on bid prices and probabilities for three rivals

Rival 1: PSL			*Rival 2: SPP*			*Rival 3: Reliable*		
Bid price			*Bid price*			*Bid price*		
INRm	*US$m*	*Probability*	*INRm*	*US$m*	*Probability*	*INRm*	*US$m*	*Probability*
1,200	16.09	0.10	1,250	16.76	0.10	1,200	16.09	0.05
1,250	16.76	0.15	1,300	17.43	0.15	1,250	16.76	0.15
1,300	17.43	0.25	1,350	18.10	0.20	1,300	17.43	0.15
1,350	18.10	0.20	1,400	18.77	0.25	1,350	18.10	0.30
1,400	18.77	0.15	1,450	19.44	0.20	1,400	18.77	0.20
1,450	19.44	0.15	1,500	20.11	0.10	1,450	19.44	0.15

Source: Disguised company information courtesy HC

Making the decision

After Mohapatra's presentation, Birari asked those assembled whether there was enough to make a decision – on whether to develop and submit a proposal. As the discussion progressed, Patil came up with a way to frame the decision:

> Since the project would roughly cost HC, INR 1,100m (US$14.75m) to execute, HC should quote a minimum of INR 1,150m (US$15.42m). Further, any bid above INR 1,350m (US$18.10m) is highly unlikely to win the contract. So, that's our range within which to place a bid.

Based on his extensive experience, Patil estimated that the likelihood of HC winning the contract at a bid price of INR 1,350m (US$18.10m) was only about 20%. If the price bid was INR 1,250m (US$16.76m), then the probability would be high – perhaps as much as 70%. At a bid of INR 1,150 (US$15.42m), the chances of winning the bid were virtually assured.

Birari acknowledged that Patil was an expert, but the complexity and uncertainty of the situation warranted more than one perspective. Birari asked each team to review Patil's estimated range of bids, identify a feasible price to quote for HC and share at least one alternative approach that incorporated all the information available to them – especially related to the uncertainty. Birari emphasized that he did not want to win a loss-making project, and nor did he want to price himself out of the market. He challenged his team, "What bid-price takes into account both the risks and the rewards?" Birari asked the team to synthesize all the perspectives – internal and external – and compare the benefits of the various approaches. Birari then adjourned the meeting, and called for a final decision-making meeting in three working days.

Keywords:
Quantitative techniques,
Project management,
Risk management,
Decision sciences

Note

1. Calculated using the average US$/INR exchange rate of 74.58 for August 2020 (Exchange Rates UK, 2020).

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Teaching notes

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Synopsis

The case describes the challenge facing Vilas Birari, the owner and chief executive of Harsh Constructions (HC), a construction company headquartered in Nasik, India. Birari had to decide on the bid for a construction project in September 2021, during the COVID-19 (COVID) pandemic. Due to successive waves of the pandemic, the state and federal governments announced lockdowns intermittently, causing uncertainty in costs related to labor, material, and project completion. The dilemma before Birari was how to set a bid price that was not so low as to incur a loss and not so high as to lose the bid to competitors. The uncertainty made Birari's decision-making complex. The case invites students to help Birari find an optimum bid price by using various quantitative techniques, such as Monte Carlo simulation and decision trees.

Learning objectives

This case can be used to teach students the application of standard management science techniques in the context of uncertainty and project management. The following objectives also align with categories in Bloom's taxonomy (Forehand, 2010), consistent with the keywords underlined.

1. How to approach uncertainty in business decisions using probabilistic calculations of cost, and profit/loss using standard probability functions. This objective maps to discussion Question 1. This objective helps students to *understand* decision making under uncertainty, as well as to *apply* basic decision-making strategies using probabilistic functions.
2. How to address uncertainty in business decisions by looking forward and reasoning backward, using the decision tree technique and the expected monetary value (EMV) of different decisions. This relates to discussion Question 2, which builds on the prior discussion in Question 1. This objective helps students *analyse* information related to risk by *applying* appropriate decision-making approaches, while explaining merits of such an approach.
3. How to analyse the risk inherent in business decisions by incorporating probability distributions for all critical variables in the form of Monte Carlo simulation. This relates to discussion Question 3. Such an approach helps students to not only *apply* a more sophisticated approach to *analyse* risk but also *evaluate* this approach relative to other decision-making approaches.
4. In addition, the case enables a qualitative discussion on risk analysis in project management in general, as covered in discussion Question 4. Here, the students are invited to *create* and develop ideas on strategic considerations that might be incorporated in the decision-making.

Position in course

This case is intended for students of management at a master's level, in an elective course on management science, which is often also known as decision science. This compact case can be positioned in the second half of the course, when exploring risk management using computer simulation as a tool. The case serves both as an introduction to using simulation to manage uncertainty, as well a contrast with simpler methods that are covered earlier in the course.

Core readings

We recommend that the instructor cover the following reading with students ahead of the case discussion, to enable a lively response to the discussion questions.

- Winston, W. L., & Albright, S. C. (2015). Chapter 9: Decision Making Under Uncertainty. In *Practical management science* (pp. 467–524). Cengage Learning.
- Winston, W. L., & Albright, S. C. (2015). Chapter 10: Introduction to Simulation Modeling. In *Practical management science* (pp. 525–598). Cengage Learning.

The instructor can substitute the above topics from other texts, if required. A non-comprehensive list of popular texts for decision science/management science include:

- Hiller, F., & Hiller, M. (2003). Introduction to management science: a modeling and case studies approach with spreadsheets (5th ed.). New York, NY: McGraw-Hill.
- Stevenson, W. J., & Ozgur, C. (2017). Introduction to management science with spreadsheets and student CD. McGraw-Hill, Inc.

Chapter numbers and topic coverage will vary, but the essence of managing uncertainty using decision science tools remains the same. For instance, in the first alternative text above, decision trees are covered in Chapter 9, while Chapter 13 deals with using simulation to manage risk.

While some of the above texts use additional simulation software, such as CRYSTAL, and @RISK, we offer the instructor a more affordable option: using the Monte Carlo simulation method in widely available spreadsheet software, such as MS Excel. The following reference provides a primer for implementing the Monte Carlo simulation in this way, in the context of project management.

- PMPeople. (2019). Monte Carlo with Microsoft Excel. Medium. https://medium.com/@pmpeople/monte-carlo-with-microsoft-excel-6a24a98bc051

Supplemental reading

While the core reading is likely to be adequate for most classroom discussions, instructors can deepen their familiarity with the topic through the following reading.

- Mantel, S. J., & Meredith, J. R. (2021). Chapter 7: Budgeting and Risk Management. In *Project management: A managerial approach* (11th ed., pp. 239–296). John Wíley and Sons, Inc.
- Qazi, A., & Simsekler, M. C. E. (2021). Risk assessment of construction projects using Monte Carlo simulation. *International Journal of Managing Projects in Business*, *14*(5), 1202–1218, doi: 10.1108/IJMPB-03-2020-0097

Finally, the first question builds on a foundational understanding of probability, and related spreadsheet functions. While most MBA curricula cover such topics as part of a core course, we provide here are a few links to primers/refreshers:

- CFI Team. (2022). NORM.DIST Function. *Corporate Finance Institute*. Retrived from https://corporatefinanceinstitute.com/resources/excel/norm-dist-function/
- Zach. (2022). How to Calculate Normal Distribution Probabilities in Excel. *Statology*. Retrived from www.statology.org/normal-distribution-probability-excel/

Additional materials

The instructor can play the following video that conveys how construction projects in India were delayed due to the COVID-related lockdowns.

- MBTV by Magicbricks. (2021, 3 May). *COVID-19 Second Wave: Will real estate projects get delayed?* www.youtube.com/watch?v=onufbHACWo0

As these delays were not restricted to India, instructors can find and play similar videos for the cultural context that is most relevant for their class.

Research methods

The case was compiled using the following information sources, all of which are cited in the "References List" section of the case.

- Interviews and personal communication with the case protagonist, Mr. Vilas Birari;
- company annual reports, interviews, and personal communication with industry executives; and
- news media and other public domain, secondary sources.

Assignment questions

Q1. Does Patil's suggested bid range of INR 1,150 to 1,350m (US$15.4m to US418.1m) resolve all the risk? Within this range, does HC still run the risk of making a loss?
Note: The conceptual underpinnings for approaching this question are available in Chapter 10 of the recommended text, as well as basic textbooks in statistics, as provided in the Core Reading section.

Q2. Within Patil's range, what price point might yield the greatest returns, given the uncertainty of winning the contract?
Note: To analyse this question, concepts available in Chapter 9 of the recommended text will be helpful.

Q3. Develop a simulation-based approach to identify an optimum solution for HC's bidding dilemma. What are the strengths and drawbacks of such an approach relative to the prior approaches?
Note: Chapter 10 of the recommended reading and the article on Medium are both relevant for approaching this Question 3.

Q4. What other factors do you think should be considered in the decision-making process? Are there other strategic considerations that Birari could ask his team to address?
Note: This discussion builds on the concepts covered in previous discussion and does not require a specific chapter from the text.

Suggested teaching strategy

Birari had to deal with an unusually high level of uncertainty, while pitching for a construction contract, all of which crystallized in the need to identify a bid price to propose to the client. The optimal bid was driven by two factors:

1. the risk involved due to the total costs to be incurred; and
2. the probabilistic nature of the competitors' bids.

The instructor can guide the discussion by a progressively more sophisticated use of the decision science toolkit. As the discussion progresses, the instructor can gradually add complexity, by incrementally adding variables to the decision problem. The assignment questions are sequenced to follow this approach.

1. *Opening (10 min)*: An energizing way to start the class is to highlight the dilemma of the protagonist, Birari, by way of a class vote. For instance, the instructors could ask the class: "Vote on one of the following four options for Birari's bid".

- Less than INR 1,150m (US$15.4m [[1]])
- Between 1,150 and 1,250m (US$16.8m)
- Between 1,250 and 1,350m (US$18.1m)
- More than 1,350m (US$18.1m)

The voting can be operationalized using a simple show of hands, or through online software such as menti.com. The instructor can then request a student to explain why s/he voted a particular way. Instructors can use the resulting response to frame the central dilemma: If Birari were to quote a higher price, HC's profits would likely be higher, but the risk of losing the order would also increase. Conversely, if Birari were to quote a low price, the probability of winning the order would increase, but also the risk of making a loss on the project.

2. Discussion Question 1 (15 min): After the opening, the instructor can ask if the bid range suggested by Patil is risk free? This leads first to a more general discussion on the nature of risk, and its drivers in this context. Returning to the assigned question, the instructor can suggest using basic probability distributions to assess the risk of incurring a loss, at a few discrete points within Patil's bid range. The calculations could lead to two important insights: As the costs are uncertain, so are profits, which implies that there are no safe points in the bid range – there is some risk throughout, while our first approach helped us assess risk of loss at various bids, it stops short of suggesting which price to bid in turn, this allows the instructor to ask a segue, "What about maximizing profits for HC?"
3. Discussion Question 2 (20 min): Having transitioned from risk of loss analysis to an analysis of maximum profits, the instructor can move to an approach that integrates the risk and opportunities inherent at different bid prices. Given the positioning of the case in the course, students should be familiar with the decision tree approach (covered in Chapter 9 of the suggested reading). This question then requires an application of the decision tree approach to the specific context of Birari's bid. Having arrived at an optimum bid price, the instructor can guide the discussion to what drivers of uncertainty are still unaccounted for, and then transition to the use of simulation as an advanced method of managing risk.
4. Discussion Question 3 (30 min): The instructor may now invite the students to evaluate the strengths of the Monte Carlo simulation method, relative to the prior approaches. It should become clear that the method of simulation (covered in the Medium article and Chapter 10 of the text) allows us to integrate not only the upside probabilities of winning the bid but also the probabilistic nature of costs, which were not addressed using the decision tree approach. The method also accommodates the likelihoods of competitors pricing at various levels.
5. Discussion Question 4 (10 min): The quantitative analysis assists a manager with managing decision-making under uncertainty, but the more strategic aspects of decision making necessitate a qualitative discussion. Thus, the instructor can facilitate a discussion on other factors that might change the nature of decision (price point) that had been identified above.
6. Closing (5 min): The session could conclude by informing the students about what did HC finally quote and whether they won the bid or not. The instructor can summarize the learnings from the discussion.

Analysis of assignment questions

Q1. Does Patil's suggested bid range of INR 1,150 to 1,350m (US$15.4m to US$18.1m) resolve all the risk of bidding for the project? Within this range, does HC still run the risk of making a loss?

To help the students get started, the instructor could ask a broad question such as, "What does making a loss imply?" and "What would you have to believe about costs, relative to a quote/revenue of INR 1,150m (US$15.4m)?" Students should be able to identify that a loss implies that the costs exceed the bid price, for example INR 1,150m (US$15.4m). The instructor could confirm this conception by suggesting that for the purposes of the case, we can take "loss" to be an operating loss, as covered in prior courses and texts in financial accounting (Pratt & Peters, 2017), which state that an operating loss (or profit) is the net amount of operating revenues and operating expenses. In the case of HC, this loss would imply the bid price net of project expenses or costs.

The instructor can then develop this issue by asking, "Can we quantify the risk of making a loss at the price point of INR 1,150m (US$15.4m), given some basic information about project costs?" The students should be able to identify project costs on average, of INR 1,100m (US$14.75m), from Table 3 of the case. On the face of it, this looks good for HC, as even at a low-bid of INR 1,150m (US$15.4m), they make a profit. But some students might point out that the costs for the project were uncertain, with a range around the expected value. If this is not raised by the students, the instructor can ask, What about the uncertainty? How do we account for the range in Table 3?

This also gives the instructor an opportunity to clarify the concept of uncertainty: as mentioned in the first chapter of the supplemental text (Mantel & Meredith, 2021), uncertainty refers to the *lack of certainty in predicting an operational variable*, such as project cost, time and scope. The range of predicted costs provided in case Table 3 underscores the uncertainty for Harsh. Returning to the assignment question, the instructor can point out that Table 3 provides not only a range of costs, but a measure of dispersion: the standard deviation of INR 60m (US$0.8m). Thus, the ask can be restated as follows: What is the probability of the project cost (mean = 1100, standard deviation = 60), overshooting the quote of 1,150, which is the low end of the bidding range?

At this point, the instructor can point out that Table 3 only provides three data points: minimum, maximum and expected (or mean). From this data, the instructor could ask what type of distribution can be inferred. The answer is – no clear one. The distribution could take on a triangular form, beta or a number of other possibilities. Ideally, we would need more data to verify a normal distribution. Given the scarce data set though, the class needs to make reasonable assumptions and select a distribution that can be the basis of assessing the risk of loss. While most of the students may have covered this in a required course on statistics or quantitative methods, instructors may need to remind them of the normal distribution, which is a bell-shaped curve that appears in a very wide variety of settings. While the three data points are insufficient to prove a normal distribution, the data gives us no reason to discard the possibility, and given its frequency of occurrence, we can use it as a starting point of our assessment.

To operationalize the above discussion, the instructor can encourage the class to find the area under the curve in Figure 1, which represents the probability of project costs exceeding INR 1,150m (US$15.4m), and thereby incurring a loss.

In Microsoft Excel (Excel), this probability can be estimated by using the 'NORMDIST' function as follows, which returns the normal distribution for a specified mean and standard deviation.

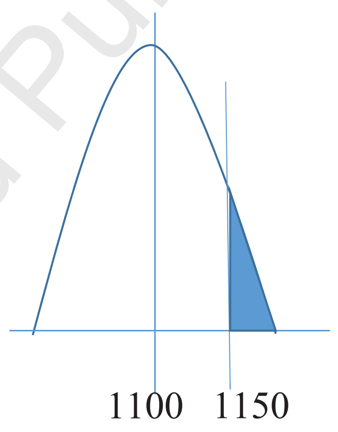
$$= \text{NORMDIST}(1150,\ 1100,\ 60,\ \text{TRUE}) = 0.798$$

However, skilled students will realize that the NORMDIST distribution gives us the unshaded area in Figure 1. Thus, the probability of loss – the shaded area in Figure 1 – is given as follows:

$$= 1 - \text{NORMDIST}(1150,\ 1100,\ 60,\ \text{TRUE})$$

$$= 1 - 0.798 = 0.202 \text{ or } 20\%$$

Figure 1 Illustrative, normal distribution of project costs



Source: Created by the authors based on case facts

This can be interpreted as the chance of incurring loss if HC were to bid at the low end of Patil's range. At this point, the instructor can ask participants to continue their calculations for other bid points: 1,200, 1,250, 1,300, and the maximum of 1,350. The class can quickly calculate the probabilities of loss as 5%, 1%,and almost zero 1300 onwards, respectively. The instructor should point out the intuition behind this – as the bid price quoted increases, the difference between the price and cost will increase, reducing the likelihood of loss.

Optional: What is the price to be quoted if the probability of loss should be within a specified value?

The instructor can also demonstrate the use of the NORMINV function in Excel, which calculates the inverse of the normal cumulative distribution. Here, the objective might be to specify a maximum risk of making a loss on the project (say 10%) and calculate the bid price that limits the risk to the stated threshold, which is a more realistic scenario. As we are interested in the probability of *not making a loss*, the input required for the function is 100% – 10% = 90%

$$\text{NORMINV}\,(90\%,\ 1100,\ 60)\ =\ \text{INR 1180 million (USD 15.82 million)}$$

The instructor can then ask the students, especially those who had answered the opening question with a low bid – Should we go with a high bid to minimize the risk of loss? Are we missing anything?

Students should be able to echo Birari's big concern: "bidding too high could increase the chances of losing the bid altogether." Thus, the gap in the analysis is that we have not yet factored in the other side of the dilemma; the likelihood of losing the bid if a high price is quoted. This enables the instructor to transition to discussion Question 2.

Q2. Within Patil's range, what price point might yield the greatest returns, given the uncertainty of winning the contract?

While the approach we used in Question 1 helped us minimize the risk of bidding too low and incurring operating losses, it was silent about the opportunity of making an operating profit by bidding at a higher price. To get a more balanced view of risk and opportunity, students can be asked to conduct a decision tree analysis across a range of bid prices. As mentioned in the core reading (Winston & Albright, 2015), the decision tree is a powerful graphical tool "[...] that enables the decision maker to view all important aspects of the problem at once: decision alternatives, the uncertain outcomes and their probabilities, the economic consequences, and the chronological order of events." After mapping out these events and outcomes, the decision maker can estimate the path among the decision branches that yield the best overall outcome, which in this case would be the maximum expected monetary value of operating profit.

To get the class to start the analysis, the instructor can suggest a simple task: to compare two prices from Patil's range – INR 1,350m and INR 1,250m. The instructor can ask the class to integrate not only the project costs but also the probabilities of winning the bid for each of the two price points. Here, we can take a single, "expected value" of costs. On the revenue side, we can incorporate the bid-winning probabilities of 20% for the quote of INR 1,350m (US$18.1m) and 70% for INR 1,250m (US$15.4m). These were estimated by Patil in the section "Making the decision".

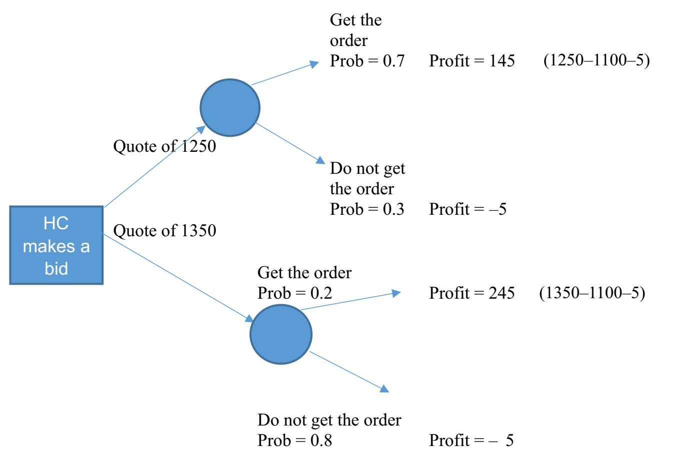
Now, the students can be encouraged to develop the decision tree beginning with two forks – quote of INR 1,250m and INR 1,350m (US$15.4m to US$18.1m). Probabilities and payoffs net of costs are drawn in the decision tree shown in Figure 2. The decision tree approach enables students to clearly visualize two of several possible paths, and each of the corresponding outcomes, probabilistic nature of outcomes and the resulting monetary payoff of each option. As the outcomes are not definite, the net payoffs are probabilistic and are commonly known as EMV.

After the two bid options are mapped, the instructor can guide students to identify the best of the two options, given that HC's objective is maximization of profit. The instructor can also remind the students to include the bidding cost of INR 5m (US$0.067m) in their decision tree. If HC loses the bid (does not get the order), then the cost of bidding is a loss. The resulting expressions for the two bid options are:

$$\text{EMV of quoting 1350} = (245) * (0.2) + (-5) * (0.8) = 45$$

$$\text{EMV of quoting 1250} = (145) * (0.7) + (-5) * (0.3) = 100$$

Figure 2 Decision tree analysis



Source: Created by the authors based on case facts

Hence, quoting INR 1,250m (US$16.76m) is a better option than quoting INR 1,350m (US $18.10m). At this point, the instructor can ask the students whether HC should go with the superior bid of INR 1,250m (US$16.76m). Stronger students would hesitate as they might be able to sense some of the shortcomings of the decision tree approach. If needed, the instructor can offer the following prompts to help the students identify the gaps in the current approach:

- What about 1,260m? Is that better or worse that 1,250m? And how about 1,240m? This should help the students realize that the decision tree approach would need to work out several other price points to identify a global optimum. While it does a good job of comparing two discrete bid points, the reality is that Birari can choose any price between. Hence, decision trees are best used for discrete events and outcomes and are not as useful when trying to identify a winning choice from a continuous range.
- What about using the standard deviation of INR 60m (US$0.80m) around the expected value of costs – INR 1,100m (US$14.75m)? Can we use the standard deviation here? Again, the limitations of the decision tree become clear – it only allows for a point estimate of costs – INR 1,100m (US$14.75m). The instructor can press for why this is the case. Again, based on the previous discussion, it becomes apparent that while decision tree can easily handle discrete probabilities, e.g. the 20% likelihood of winning the bid at INR 1,350m (US$18.10m), it fails to deal with continuous probability functions, e.g. the mean cost of INR 1,100m (US$14.75m) with standard deviation of INR 60m (US$0.80m).
- Further, the discrete probabilities mentioned in the case were Patil's best estimates. They did not explicitly account for competitors' moves and probabilities, as outlined in Table 4 of the case. Hence, while the decision tree is handy, it has limitations, which motivate us to explore other analytic tools, such as the Monte Carlo simulation.

Q3. Develop a simulation-based approach to identify an optimum solution for HC's bidding dilemma. What are the strengths and drawbacks of such an approach relative to the prior approaches?

Through the first question, we attempted estimating the probability of making a profit/loss separately at a few discrete bid values for varying/probabilistic project costs. The second question helped estimate the expected profit/loss collectively for a few discrete bid values at an average cost of the project. The instructor can ask the students if the analyses performed so far are sufficient to arrive at for an informed decision by HC. Students should point out that in the first question the expected profit was not estimated and in the second question the variation in costs were not considered. Furthermore, only a few discrete bid values were considered for the estimation so far.

While the decision tree approach did balance the risk of losing the bid by bidding too high and the risk of making a loss by bidding too low, it did not consider the variation in project cost and was based instead on the expected or average cost. It also did not consider the cost arising out of delay in project duration and consequent penalty. As these probabilities/ uncertainties are not discrete, the decision tree might not be the best approach. One approach that can incorporate multiple uncertainties, including those that are described as continuous functions, is the Monte Carlo simulation.

The instructor can then guide the students on how a Monte Carlo simulation can address the deficiencies in the analyses performed so far and can incorporate more variables. This approach – more fully described in the recommended reading (PMPeople, 2019) – uses repeated random sampling to solve complex, but defined problems. In the case of HC, the defining conditions include the range for project cost, the range of bid prices, the associated probabilities for both and the competitive bids. Said another way, the simulation approach provides not only EMV for discrete bid prices but also identifies best- and worst-case scenarios, based on multiple parameters that were input. Given these inputs, the Monte Carlo method can develop a probability distribution for each critical variable and then run thousands of simulations so that managers can focus on the distribution of potential outcomes as well as on any prediction of the most likely one.

To implement the Monte Carlo simulation in Excel, the RAND () function is key. When one enters a RAND () function in a cell, a number appears in the cell that is equally likely to assume values between 0 and 1. For example, there is a 20% chance that a number less than or equal to 0.20 appears in a cell and similarly, a 50% chance that the number appears between 0.30 and 0.80. The values in each cell are independent of the values in other cells. This is how the RAND () function models uncertainty and helps generate a range of outcomes.

The instructor can begin the process of specifying a conceptual model, which can then be simulated. The following equation provides a conceptual model:

$$Y = f(x1, x2 \& ..xn)$$

In the above equation,

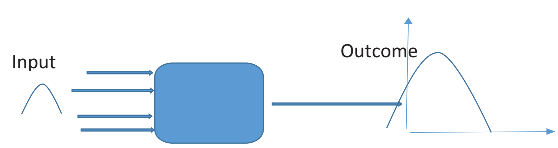
- Y denotes the outcome variable of interest: HC's profit from the bidding in the context of the case; and
- x_i are the input variables, and the class can be polled on what they might be.

The instructor can further classify the key variables as follows:

- Decision variable: the price that HC should quote to the client.
- Known variables that affect the price: cost of bidding (INR 5m) and due date 24 months and penalty of INR 5m per month of delay.
- Random (uncertain) variables: the prices quoted by competitors, project duration (uncertain due to the COVID pandemic), and project cost.

The instructor can then suggest that a simulation of the above equation would provide a solution as represented graphically in Figure 3.

Figure 3 Conceptual model for Monte Carlo simulation



Source: Created by the authors based on concepts outlined in (Richman & Coleman, 1981)

The instructor can clarify that in the simulation, we use both the known variables and the simulated random variables. In the simulation, we can also input different values of decision variables. A first step in building the simulation is to specify the function that links the output (profit) with the input variables. The instructor can ask students to specify the function, and then reveal a model answer – provided below in the form of a spreadsheet equation.

$$\text{Profit} = (\text{If HC price} <= \text{Min (competitor price), HC Price} - (\text{cost of contract bidding cost} + \textit{penalty for delay}), \textit{ELSE} (-\textit{bidding cost}))$$

The above equation, with minor modifications (e.g. omit the 'ELSE', which was added for clarity, but is not required in Excel), can be programmed into a spreadsheet program. The instructor can guide the students to operationalize the simulation in MS Excel as explained in Exhibit 2.

It can be observed that the average profit HC can make for a quoted price of INR 1,250m (US$16.76m) is about INR 120m. Please note that this value will not be exact, given the probabilistic nature of the exercise. Approximate average profits for quotes by HC are mentioned in Table 5. It is clear that HC can maximize its profit by bidding for the contract at INR 1,250m (US$16.76m).

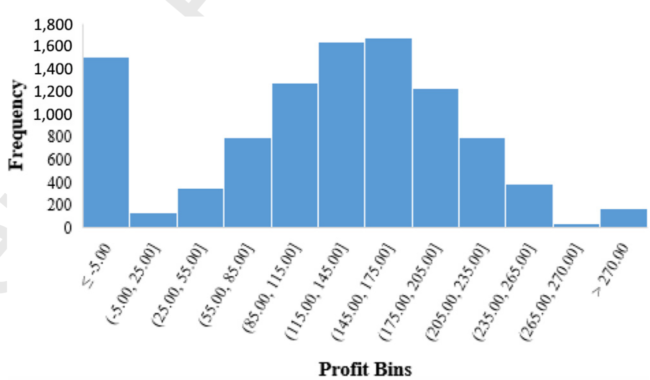
The distribution of profits for each of the quotes can also be presented as a histogram. The histogram for the bid price of INR 1,250m (US$16.76m) is presented in Figure 4. This instructor can encourage the participants to draw histograms for all the price quotes.

Table 5 Bids and average profits

Harsh Constructions			
Price quotes		*Approximate average profit*	
INRm	*US$m*	*INRm*	*US$m*
1,150	15.42	44	0.59
1,200	16.09	94	1.26
1,250	16.76	120	1.61
1,300	17.43	100	1.34
1,350	18.10	55	0.74
1,400	18.77	12	0.16
1,450	19.44	–2	–0.03

Source: Created by the authors based on analysis of case facts

Figure 4 Distribution of profit in INR millions for bid of INR 1,250m (US$16.76m)



Source: Created by the authors based on analysis of case facts

The instructor should interpret the above Figure 4 as representing that a bid price of INR 1,250m (US$16.76m) represents a strong bid, which balances the risk of cost overruns with a likelihood of winning the bid and making a profit of INR 120m (US$1.6m). At other price points, the trade-offs between various risks reduce the EMV.

The instructor can point out that Figure 4 also strikes a cautionary note: the optimal bid price of INR 1,250m (still has a probabilistic range of profits associated with it, driven by the very uncertainties considered.

Q4. What other factors do you think should be considered in the decision-making process? Are there other strategic considerations that Birari could ask his team to address?

The instructor can reiterate that the simulation approach enabled an optimization that took into account multiple sources of uncertainty, such as competitive pricing, project timing uncertainties related to the pandemic and revenues and possible penalties. The instructor can then invite the class to identify other factors that Birari should/could consider beyond the factors and uncertainties already covered. For each new idea that the class generates, instructors should also probe on how to incorporate it into an analysis, which could result in an action plan for Birari. An illustrative list of such ideas and approaches are provided below:

- *Variability of underlying data* related to competitor and customer response. While multiple runs of the simulation were able to find stable, optimum solutions for the bidding process, one cannot discount the possibility that the basis of the simulation – underlying estimates of competitor and customer responses have embedded uncertainty. This can be addressed by conducting scenario analysis by varying the underlying data and checking how the optimum bid might change. This might also inspire the organization to gather more information related to the competitor and customer intelligence, to improve confidence in the underlying data.
- *Relative risk-reward profile of the project*: While the current project might be emblematic of risk encountered in other projects during the pandemic, HC might still need to check if the project fits a desired risk-reward profile within its project portfolio. This could include comparisons related to returns as well as risks/penalties of the current project relative to the portfolio average. However, the portfolio average might not be representative of the prevailing conditions during the pandemic. Hence, the portfolio average might need to consider a smaller, more recent sample.
- *Relationship and brand building*: If Birari believes that the client could float more construction-related RFPs, this could be an important factor. To confirm this possibility, HC would need to gather more information about the client and engage in a dialogue with multiple stakeholders at the client. In these conversations, it would be important also to assess if the client placed a premium on supplier reliability and the likelihood of repeat business if the current project were executed to the client's satisfaction.
- *The need to consider the orders on hand and the level of fixed resource utilization.* If orders on hand is low and resources are idle, the company cannot take the risk of quoting high and losing out the order. They can consider the marginal cost or incremental cost to give a very competitive bid.
- *Likelihood of payment/penalties:* Building on the idea of portfolio of orders or projects-on-hand, some students might raise the idea of quality of the cashflow. For instance, especially in emerging market contexts, the timeliness of payments (receivables realized) from a government client, is quite poor. A private client with reliable cash flows might be preferable, from the perspective of time value of money.
- *Impact of competitors using similar tools*: Assuming HC's rivals had similar access to decision science tools and spreadsheets, how would that change our analysis as HC? At one level, the instructor can suggest that game theory – typically beyond the scope of a course in decision science – would be the appropriate tool to model competitor behaviour. However, a simpler argument is that case facts related to competitor behaviour – their risk appetite, projects on-hand and cost considerations – might already be incorporated in their bid ranges and associated probabilities.

- *Interaction between variables:* Our decision-making approach assumed that changes in one variable did not impact others. For instance, the price quoted by HC did not impact the cost structure. In practice, however, this assumption is not strictly true. Such complexity is beyond the scope of the current discussion and is not required for projects of the scale being discussed in the case. However, for large projects these interactions can significantly impact the outcomes. The instructor can suggest that this can be addressed by embedding this complexity into more complex simulations, as well as using system dynamic modelling, using specialized software.

Teaching in an online setting

As a complement to the above teaching plan and analysis sections, we offer the following guidance, similar to the above general plan. We assume that the instructor is using an online platform that, at a minimum, allows for an oral discussion as well as sharing/presenting of the instructor's screen. The ability to use breakout rooms would be of added value.

1. The class voting mentioned in the opening section can be administered using an online polling tool. For example, www.mentimeter.com is a popular choice, as are the built-in polling tools within Zoom and Microsoft Teams. On capturing participants' preferences, instructors can record inputs on a blank slide while sharing their screens.
2. For Assignment Question 1, the instructor can share his/her screen while performing the calculations for the probability of loss for at least one bid. For at least one more, any of the participants could be asked to share her screen and perform similar steps as before for the class demonstration. This will help participants gain more confidence in the topic.
3. Assignment Question 3 provides an introduction to Monte Carlo Simulation. As the participants might find the topic challenging, it is important that in an online setting, the instructor shares his/her screen and provides a step-wise demonstration of the simulation procedure. The demonstration can also be recorded and shared with the participants as they may want to revisit the discussion again later to gain more clarity on the topic.
4. For Assignment Question 4, breakout groups, if available, can be formed as they are a helpful way for learners to discuss other factors that Birari should/could consider to price in uncertainty. The instructor can then record class input on a blank template version of Exhibit 1 while sharing the screen with the learners.

After discussion, the instructor can move to updates (see below).

What happened

In the last week September of 2021, HC made a bid for the project, which was in the range of INR 1,240m to INR 1,270m. In October of 2021, SPJIMR awarded the project to HC and construction began soon after. The Omicron wave of the pandemic, which hit the Indian state of Maharashtra in December of 2021, caused social restrictions and delays in the project (Sabarwal, 2022). Despite the delays, the project was reported to be on schedule, in July of 2022.

Key takeaways

The case helps the participants learn how to make decisions under uncertainty. Multiple probabilistic approaches to bidding for a project are described in the case, such as loss probability estimation using normal cumulative distribution, expected monetary value calculation using the decision tree approach and Monte Carlo simulation. However, if one ignores the qualitative factors that might influence the decision, it will be at one's own peril.

Exhibit 1. BOARD PLAN

Figure E1

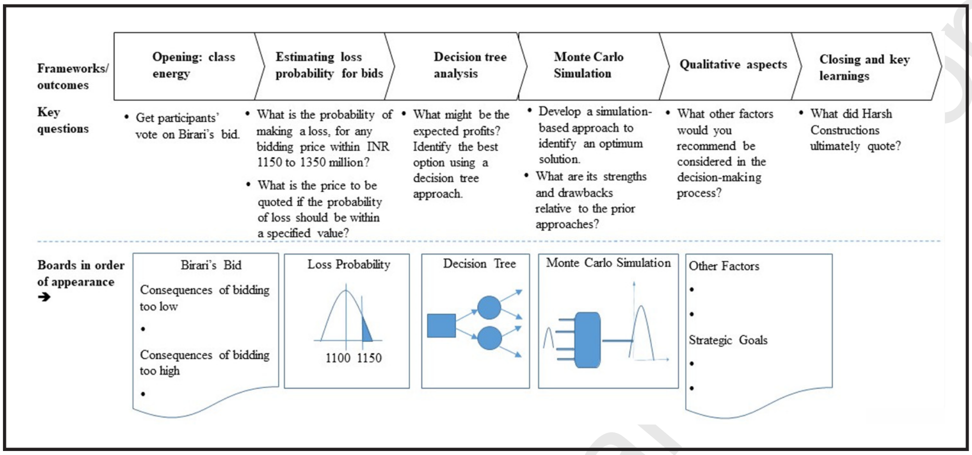


Exhibit 2

Instructors can ask students to open a new Excel workbook. To run the Monte Carlo simulation, the Excel sheet must be prepared with the information provided in the case regarding the competitors' quotations and their probabilities, project duration completion probabilities, and the other constant values such as the delay cost of INR 5m per month and bidding cost of INR 5m.

The above simulation can generate many possible outcomes for each set of input values. The greater the number of simulations, the better the stability of the outcome. With modern PCs, 10,000 runs of the simulation should take only a couple of minutes, and provides a good checkpoint for testing the stability of outcomes. This process can be repeated for different values of price quoted and from all stable outcomes, a final bid price that yields maximum profit can be selected.

The following steps could help prepare the spreadsheet to perform a Monte Carlo simulation:

- The instructor can ask the students to copy Case Table 4 information in the workbook for the competitors' quotes with probabilities.
- PSL's quotes and their probabilities are copied in consecutive columns in the cell range D8:E13.
- Add another column before column D to calculate cumulative probabilities for the quotes. Enter the value 0 in cell C8. In cell C9, type the formula = C8 + E8 and copy the formula from C9 to C13 to calculate the cumulative probabilities of the quotes. The cumulative probabilities in column C describe the range of probabilities less than or equal to the mentioned level for the corresponding quotes. For example, the cumulative probability of 0.25 in C10 describes that the probabilities including and over 0.1 and less than 0.25 will receive the quote of 1,250.
- Repeat steps ii and iii for the quotes of SPP and Reliable to fill the columns F8 to H13 and I8 to K13, respectively.
- Follow the same process for Project Duration data from Case Table 2, as for the quotes in steps ii and iii, and paste the data in the cell range N8:P15.

To run the Monte Carlo simulation to calculate the expected profit for Harsh Constructions, do the following:

- Enter the integers 1 through 10,000 (corresponding to the 10,000 "iterations" of recalculating the spreadsheet) in the range B21:B10020 (a larger number of iterations can provide a more stable solution). Next, enter 1 in B21, and from the Home tab, select Fill and then Series. Choose "Columns" under "Series in", "Type" as "Linear", Step value as 1, and Stop value as 10,000. Click on OK.

- Lookup the quotes for PSL starting from cell C21 with the formula = VLOOKUP(RAND(), $C$8:$D$13,2). This step allows Excel to selecting a number between 0 and 1 randomly. Corresponding to that number from cells C8:C13, the formula returns a quote from D8: D13 to cell C21.
- Similarly, the quotes from SPP and Reliable are entered into cell D21 using the formula = VLOOKUP(RAND(),$F$8:$G$13,2) and into cell E21 using the formula = VLOOKUP(RAND (),$I$8:$J$13,2), respectively.
- In cell F21, the minimum of the three quotes from C21, D21 and E21 is captured using the formula = MIN(C21:E21).
- For HC to win the order, its quote had to be lower than the lowest of the three competitor quotes. The quote for HC could be entered in cell G18. Let us say this were INR 1,250m, for instance. In cell, G21, enter the formula = IF($G$18<=F21,1,0) to ascertain whether HC's quote was the lowest or not. If it were the lowest, HC wins the order and the formula returns 1, otherwise 0.
- In cell H21, the randomly decided project duration is entered using the formula = VLOOKUP(RAND(),$N$8:$O$15,2).
- For calculating the delay caused in the completion of the project; in cell I21, use the formula = MAX(H21−24,0), to return the positive difference between the project duration and the maximum assigned time of 24 months for completion.
- In cell J21, calculate the penalty for the delay in project completion, in case Harsh Constructions wins the order using the formula = I21*5*G21. A penalty of INR 5 million per month is levied in case the time taken for project completion exceeds 24 months.
- To estimate the Contract Cost, in cell K21, the mean and the standard deviation of the expected cost, taken from Case Table 3, are entered into the formula = NORMINV (RAND(),$S$8,$T$8)*G21, whenever HC wins the order.
- In cell L21, the Total Cost incurred is calculated by summing the Contract Cost, the Penalty, and the Bidding Cost of INR 5 million.
- In cell M21, the Profit is calculated by the formula = G21*$G$18−L21. That is the difference between HC's quote (if they win the order) and the total cost incurred in the project. Please note that if HC does not win the order, they incur a loss equivalent to the bidding cost.
- Now select cells C21:M21 and drag them down until C10020:M10020 to fill all the values.
- Calculate the average profit in cell M10021 using the formula = AVERAGE(M21:M10020).
- Repeat the process of calculating the average profit using the Monte Carlo simulation for different quotes by HC.

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Abstract

Title – *Bidding under uncertainty: Harsh Constructions.*

Learning outcomes –

1. Probabilistic calculations of cost, and profit/loss using standard probability functions
2. Decision tree to find the expected monetary value (EMV) of different options.
3. Monte Carlo simulation for risk analysis.
4. Risk analysis in project management.

Learning objectives – *Learners will be able to understand and apply the following: how to approach uncertainty in business decisions using probabilistic calculations of cost, and profit/loss using standard probability functions; how to address uncertainty in business decisions by looking forward and reasoning backward, using the decision tree technique and the EMV of different decisions; how to analyse the risk inherent in business decisions by incorporating probability distributions for all critical variables in the form of Monte Carlo simulation; and appreciation of strategic considerations in risk analysis as it applies to project management*

Case overview/synopsis – *The case describes the challenge facing Vilas Birari, the owner and chief executive of Harsh Constructions, a construction company headquartered in Nasik, India. Birari had to decide on the bid for a construction project in September of 2021, during the COVID-19 (COVID) pandemic. Due to successive waves of the pandemic, the state and federal governments announced lockdowns intermittently, causing uncertainty in costs related to labor, material and project completion. The dilemma before Birari was how to set a bid price that was not so low as to incur a loss and not so high as to lose the bid to competitors. The uncertainty made Birari's decision-making complex. The case invites students to help Birari find an optimum bid price by using various quantitative techniques, such as Monte Carlo simulation and decision trees.*

Complexity academic level – *This case is intended for students of management at a master's level, in an elective course on management science, which is often also known as decision science. This compact case can be positioned in the second half of the course, when exploring risk management using computer simulation as a tool. The case serves both as an introduction to using simulation to manage uncertainty as well a contrast with simpler methods that are covered earlier in the course.*

Supplementary material – *Teaching notes are available for educators only.*

Subject code – *CSS 7: Management Science.*