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A TALE OF TWO SIMULATIONS FOR PROJECT MANAGERS

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ABSTRACT

Project managers need to understand the impact of uncertainties on project plans. Two techniques that can meet this need are Monte Carlo simulation (MCS) and discrete event simulation (DES). MCS uses random samples of input parameters to determine the system outputs. DES also uses random samples but models the sequence of events in a system with time modeled explicitly. Both use the results of repeated executions to determine the distribution of outputs. There has been an increasing use of MCS for evaluating the impact of uncertainties in activity durations and costs on the project's duration and total cost. There are few reports of use of DES for such purpose. This paper presents analyses of a hypothetical project using both the simulation approaches. The results show that discrete event simulation has an advantage for the scope of this study and based on the features and limitations of the software used.

1 INTRODUCTION

Planning of reasonably sized projects that last longer than a few weeks and utilize more than a handful of constrained resources can be complex. Uncertainty has a high influence on project complexity (Qureshi and Kang 2015). Major projects are generally completed over time and over budget (Flyvbjerg 2011). Project managers of course sincerely aim to be one of the minority of projects that are completed on time and within budget. The determination of target project completion date and budget hence needs to be done carefully. The schedule and the budget should be developed considering the relevant risks including uncertainties in estimated durations and costs of individual activities.

Project managers and planners commonly include time buffers in the project schedule and contingency amounts in project budgets to account for the uncertainties in the estimates (PMI 2017). There are a variety of approaches used in practice to determine the size of the time buffers and contingency budgets with predetermined guidelines being a common one (Hollmann 2009). The common procedure is to develop an initial project plan based on average or most likely durations and costs of the involved activities. The resulting project duration and budget are then increased by a predetermined percentage such as 15%, 20%, etc. to add time and cost buffers. These percentages are generally sized based on personal professional experiences and are subjective (Ortiz et al. 2019).

Simulation has been identified as an approach for determining time and cost contingencies (Hollmann 2009). Two types of simulations, Monte Carlo simulations (MCS) and discrete event simulations (DES) are primarily applicable for this purpose. MCS in this context uses random samples of activity durations and costs together with the project network relationships to determine the resulting project duration and cost. MCS also allows defining probabilistic execution paths in the project network to model alternative scenarios. DES similarly uses random samples of activity durations but models the project execution over time as a sequence of events. The explicit modeling of time in DES allows assessing the project status at desired milestones and model actions to affect the activities in the remaining project duration in simulated time. DES also allows modeling of alternate domain specific project execution approaches. DES thus allows more control than MCS over modeling alternative scenarios.

Both MCS and DES use multiple runs, with each run representing one execution of the entire project with the drawn random samples of activity durations and other inputs. The resulting project duration, cost, and other measures of interest are captured across the multiple runs to calculate probability mass functions (PMFs) for them. The PMFs can then be used to determine probabilities of achieving a certain value and confidence intervals to help define target project duration and cost that are aligned with client requirements and the organization's risk tolerance.

There is limited application in industry of simulation for determining project time and budget contingencies though there is fairly large research literature on the topic. Anecdotal evidence based on interactions with practicing project managers indicates that some large infrastructure companies employ Monte Carlo simulations (MCS) to help determine the target duration and budget for the project. There is scant evidence of use of discrete event simulations (DES) for this purpose in industry. There are reports of use of a third type of simulation, systems dynamics simulation (SDS) for evaluation of project plans (Godlewski et al. 2012). SDS usually focuses on impact of soft factors such as productivity and team morale that affect the progress based on causal feedback loops. The reported SDS applications do assess the impact of soft factors on project duration but do not generally report on PMFs or even confidence intervals for project durations or budgets.

Among the approaches mentioned above, MCS and DES utilize statistical basis for providing guidance for setting target project duration and budget. The widely practiced approach of adding a predetermined percentage is clearly simple but its value is questionable. Projects by definition are unique (PMI 2017) and the blanket use of a set percentage across all projects can under or overestimate the time and cost buffers. The focus of SDS is on evaluating effect of soft and strategic factors and is not aligned with the objective of determining the PMF of project duration and budget. It has also been pointed out that SDS is complex and not suitable for operational project managers (Williams 2004). The MCS and DES approaches may meet the need of project managers for quantifying the uncertainties in project duration and budget and are compared in this tale of two simulations.

There are business considerations that generally impact the project duration and budget. In a competitive situation, the project manager with support of their organization may reduce the duration and lower the budget thus increasing the risk of not meeting either. Such considerations are not within the scope of this paper. The availability of project duration and budget PMFs does allow the project managers to understand the increased risk of exceeding the targets following any reductions in targets based on business considerations.

The next section briefly reviews related literature. Section 3 describes a hypothetical project, the development of corresponding models using MCS and DES, and the two scenarios used for comparison. The results of MCS and DES are presented in Section 4 with additional discussions in Section 5. Section 6 concludes the paper with suggestions for further analyses.

2 RELATED WORK

The need for incorporating the effect of uncertainties in estimating the project duration was identified decades ago (see for example, McCrimmon and Rayvec 1964). Various approaches have been reported in literature to address this need. MCS is a well-accepted technique for analyzing project schedules and project risks and has been identified as such in Project Management Body of Knowledge (PMI 2017). DES has been used in academic literature for supporting project planning in a wide range of domains as indicated by recent reviews of its application for projects in business process management (Bosilj Vukšić et al. 2017) and lean and agile construction domains (Mostafa et al. 2016). A few selected efforts that reference MCS and DES are included in this section.

Williams (2004) points out the flaws in MCS that may lead senior management to question the credibility of its results. He points out that MCS models usually do not model the actions taken by the project managers when the project is running late. The generated PMF of project duration appears much wider than it is ever seen in reality and that may lead to the credibility question. He also points to the need for modeling the effects of the causal loops that may be triggered by the actions taken to expedite the project.

Nahrvar (2010) compares MCS and DES in the estimation phase of a mega project. He identifies the ability to define and allocate resources as a key advantage that DES has over MCS. However, the DES model built for the case study in the work doesn't include modeling of resources to maintain compatibility between the DES and MCS model structures and input data. The study concluded that under such settings the two approaches lead to similar results. Riley (2012) lists several advantages of DES over MCS including the ability to dynamically address emerging bottlenecks, constrained resource allocations, and stochastic events, and using optimization routines with the DES model as a platform.

Researchers in construction project management appear to have utilized DES perhaps more than for projects in other domains. CYCLONE, a DES tool for construction projects was developed in mid-seventies (Halpin 1977) and others have followed over the years (Du et al. 2016). In fact, researchers went on to build further on top of basic DES applications. AbouRizk and Wales (1997) combined DES and continuous simulation for construction project planning with the goal of going beyond individual use of MCS or DES. They simulated an example project in daily steps and used a continuous process for determining the day's weather and a neural network to determine weather's effect on productivity. They automated some of the analysis steps but pointed to the substantial additional effort required for the enhanced project planning.

Lee and Arditi (2006) present a stochastic simulation-based scheduling system (S3) that allows comparison of project duration estimates generated by critical path method (CPM), program evaluation and review technique (PERT) and DES. Interestingly, for the two case studies the authors modeled only the impact of activity duration variabilities on project duration and didn't use any additional flexibilities offered by DES. In such use, DES would generate the same or close to the same results as MCS. Lee et al. (2012) extended the system to AS4, an advanced version to facilitate the use of simulation for project planning purposes by automating the task of identifying distributions for activities, executing the simulation, and identifying the best fit distribution for the project duration. Though they didn't identify it by name, the description of the steps suggests that they used MCS and not DES. The two provided case studies did not appear to include modeling of resource constraints.

A review by Derbe et al. (2020) of 332 papers on construction project scheduling published over the last decade (2009-2019) did not identify DES as one of the major keywords, defined as those that occurred at least 3 times. The keyword MCS occurred 8 times with 2017 as the average publication year while the keyword "simulation models" occurred 3 times with 2012 as the average publication year. The bibliometric network of keywords provided in the paper links "simulation models" to "project planning" and "risk management" and that suggests the simulation models may have included DES models for evaluating project plans. Overall, the keyword results from the review suggest that at least for construction project scheduling research MCS continues to be a relatively popular technique while that's not the case for DES. The implication regarding DES is surprising and is perhaps based on the selection of the journals that were identified by the authors as being relevant to the topic.

Interestingly, there have been a number of publications comparing Markov Modeling (MM) to DES in healthcare. The work is of interest since the Markov process is implemented by some of the researchers as an MCS using Crystal Ball, an Excel add in (see for example, Karnon 2003). The implementation effort can thus be seen as similar to that for MCS for project management applications using Crystal Ball and similar other Excel add ins. Standfield et al. (2014) review 22 publications to conclude several advantages of DES over MM including the ability to model queueing for constrained resources and accommodating complexity and uncertainty. They also identified some disadvantages of DES compared to MM including increased data requirement and model development, validation and model execution times. The conclusions are parallel to those drawn in publications comparing DES to MCS mentioned above.

Overall the brief literature review suggests that DES may have advantages over MCS for project planning and execution but these advantages need to be highlighted particularly for practitioners and researchers in domains other than construction. This paper compares MCS and DES using a hypothetical generic project with the intent of avoiding the use of any domain specific mechanisms that provide a bias towards either MCS and DES.

3 APPROACH

The comparison of MCS and DES has been carried out across two scenarios of a hypothetical project. This is an initial step for the comparison. This initial step may identify the need for future efforts for comparing the two simulation paradigms across multiple project examples with different characteristics.

3.1 Hypothetical Project Description

The hypothetical project used for this study has been adapted from a group assignment for a graduate level class on project planning and scheduling. The project has 31 activities each with stochastic times. The activity duration means range from 4 to 120 days. The activity durations have different specified distributions including Normal, Triangular, Beta and Uniform. There are 5 resource types, R1 through R5, with costs ranging from $10 to $50 per hour. Each activity has specified requirements varying between 1 to 5 units each of 3 to 5 resource types. The resources are required to be available together to start and execute the activity. There is no preemption of resources during the execution of an activity. The network for the hypothetical project is shown in Figure 1. The critical path in the figure has been identified based on activity durations at their mean times and with no resource constraints.

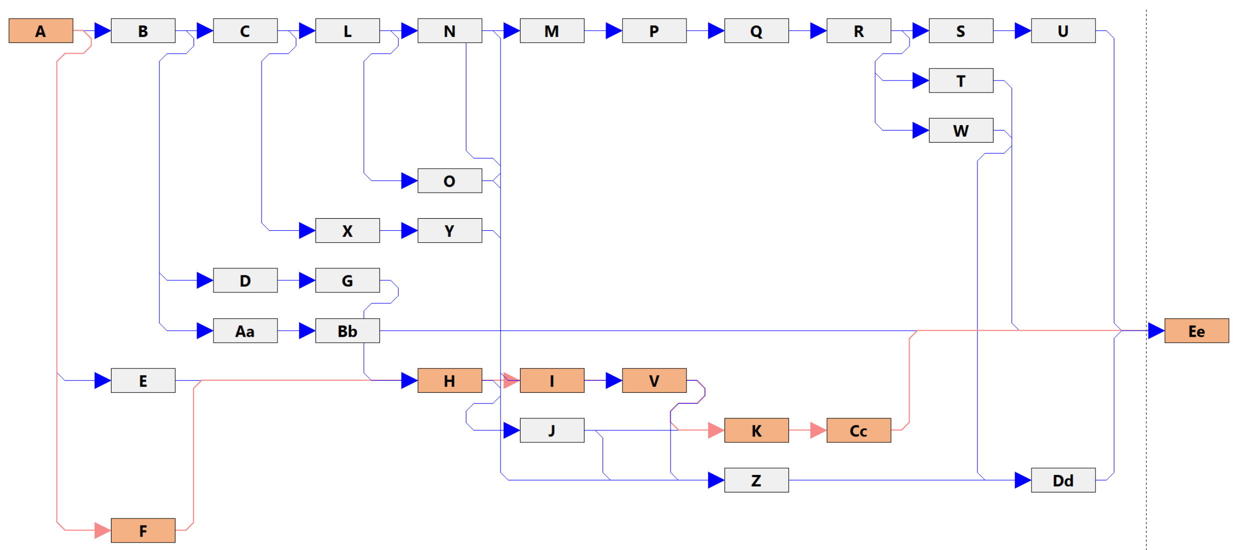


Figure 1: Network for the hypothetical project.

The project plan with unconstrained resource availability has resource requirements ranging from a peak of 12 units for R5 to 23 units for R2. The project duration with unconstrained resources and deterministic activity durations set at their mean values has a duration of 228 working days. This will be referred to as the unconstrained deterministic scenario going forward.

The resources are constrained with their initial availability at 10 units each. The project duration with the constrained deterministic scenario as generated via leveling the resources using Microsoft (MS) Project Professional 2019 is 370 working days. The peak resource units after leveling are at 9 or 10 units across the 5 resources. It should be noted that MS Project uses some internal heuristics to develop its solution for the resource constrained project scheduling problem (RCPSP) described above. Other project planning software and RCPSP heuristics may arrive at different solutions with a duration more or less than 370 days.

3.2 Project Manager's Objectives

A project manager placed in charge of the hypothetical project described above can be provided multiple objectives based on the context that can be categorized as scope, time, or budget driven. In general, though the objectives may require a balance between time and budget while meeting all the scope. A project schedule is generally developed using a software (such as MS Project or Oracle Primavera or any of a large number of other project planning software). The generated schedule is usually then enhanced to include time and cost buffers to account for uncertainties such as the stochastic activity durations and a range of risk factors that may impact the project progress. The final version of the schedule is shared with the internal or external client as applicable. Once the schedule has been shared with the clients, the project manager does their best to ensure that the project is finished by the defined project completion time (PCT). One of the primary metrics for assessment of the performance of the project manager and the team is their ability to finish the project by the agreed-on PCT.

The determination of the PCT that is shared with clients has to be done carefully. A target PCT may be defined by the organization based on client needs. The project manager may be provided some flexibilities if the target CT appears to be aggressive based on the internally generated project plans. The project manager needs to determine and inform the management of the chances of finishing the project by the PCT. Essentially, project managers need a way to determine the confidence levels associated with the different scenarios. As briefly described in Section 1, MCS and DES may be used to determine the confidence levels.

It is assumed that project manager's objectives for this study are to complete the project in 350 days with some budget flexibility available to add resources if needed to meet the PCT. The project manager would like to ensure that there is a high confidence level in achieving the PCT considering the resource constraints and stochastic activity durations. No additional risk factors beyond the variability in activity durations are considered for this study.

3.3 Comparison Scenarios and Software

The comparison of MCS and DES has been carried out using the scenarios and software identified in Table 1.

Table 1: MCS and DES comparison scenarios and software.

Scenario	**Resources**	**MCS software**	**DES software**
1. Base Case	Constrained	@Risk	ExtendSim
2. Crashing with Additional Resources	Constrained with increase allowed if needed	@Risk	ExtendSim

3.4 MCS Model Development

The MCS models for this study have been developed using the academic version of @Risk software from Palisade. @Risk is an add-in to MS Excel. The version 7.5 of @Risk used for this study allows a direct import of the plan from MS Project (the import capability is not available in the recently released version 8.0 of @Risk). Once the plan has been imported in to @Risk, the deterministic activity durations can be replaced with corresponding stochastic specifications with applicable distributions. User can identify cells of interest such as project duration and budget as output cells and run the simulations for desired number of iterations. Once the simulations runs are complete, the users can examine the empirical distributions for duration and budget and any other identified cells of interest. The distributions can be used to identify the confidence level associated with achieving specific durations and budgets. Section 4 includes screenshots of distributions generated by @Risk.

3.5 DES Model Development

The DES models were developed using ExtendSim Pro 10.0.6 from Imagine That Inc. ExtendSim is a general purpose software that allows continuous, discrete rate, and discrete event simulation with models built using drag and drop of appropriate blocks from available libraries to represent the system being modeled.

The hypothetical project was modeled in ExtendSim by using appropriate blocks and connecting them based on the precedence network of the project. Resource pools were used to model the five types of constrained resources. Hierarchical blocks were used to represent activities with single, two, and three successors. These hierarchical blocks were replicated and connected directly for single predecessor case and using merge nodes ("Batch" block in ExtendSim) for multiple predecessor case to build the project network as shown in Figure 2. A flow unit enters the start node of the network and simulates execution of successive activities. Following simulated completion of an activity the flow unit splits into as many successor activities as are present. The flow units merge together at merge nodes immediately before the activities that have multiple predecessors. The exit of the flow unit at the end node of the project network indicates completion of the project. Multiple copies of the model were made and modified to represent the project with deterministic activity durations, stochastic activity durations, and the increase in resources if the project is assessed to be running late.

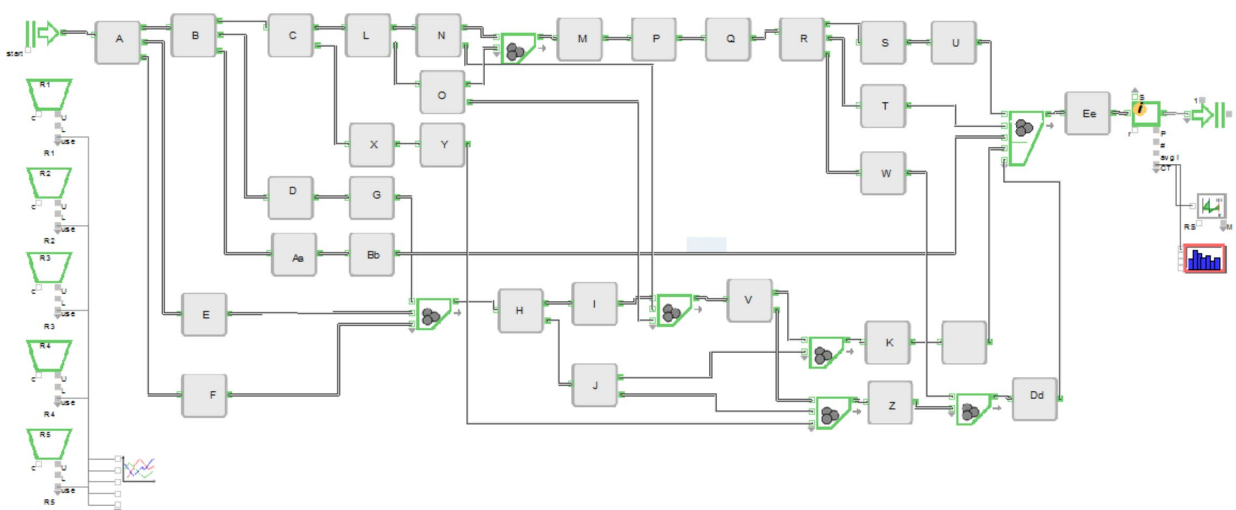


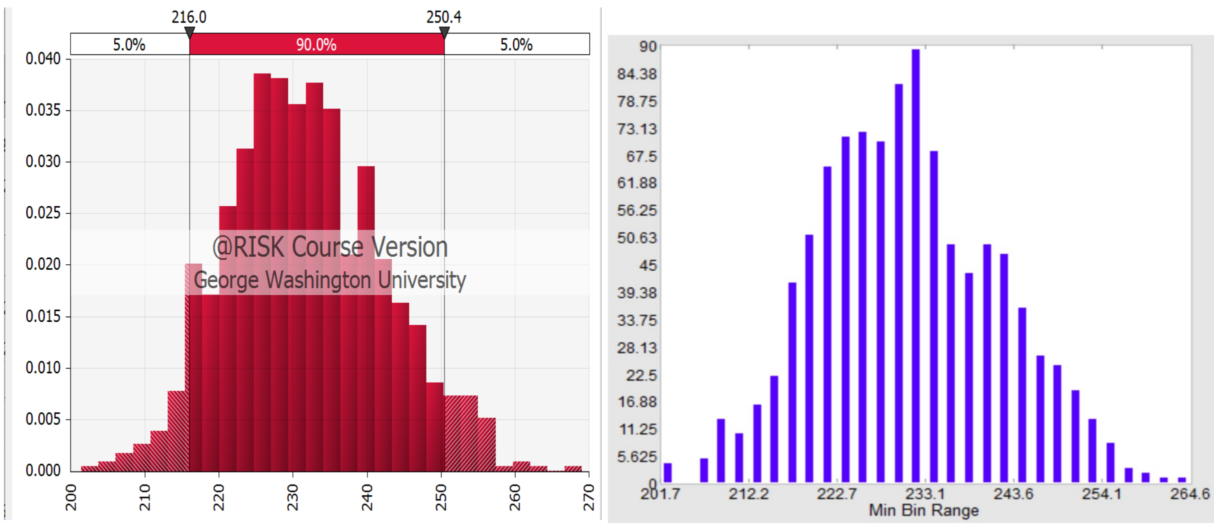
Figure 2: ExtendSim model of the hypothetical project.

4 SIMULATION RESULTS FOR THE TWO SCENARIOS

The results for the two scenarios listed in section 3.3 are discussed in this section. Before embarking on runs for the two scenarios with constrained resources, initial runs were made with unconstrained resources for deterministic and stochastic activity durations. The deterministic duration runs served as a verification of all the data and precedence relationships being defined correctly across the two software. Results from the two software matched exactly on durations (228 days), total work per resource, and total cost ($2,056,800). The stochastic duration runs similarly verified that the two software generated similar project duration measures as shown in Table 2. ExtendSim and @Risk generated similar distributions for these runs as shown in Figure 3. The results in Table 2 and Figure 3 are based on 1000 replications each.

Table 2: Agreement in results of initial runs with unconstrained resources and stochastic activity durations.

Simulation Paradigm	Software Used	Project Duration in Working Days			
		Mean	5-percentile	50-percentile	95-percentile
MCS	@Risk	232.2	215.7	231.8	250.3
DES	ExtendSim	232.0	215.4	231.6	250.6



(a) (b)

Figure 3: Project duration histograms for initial runs with unconstrained resources and stochastic activity durations from (a) @Risk and (b) ExtendSim.

4.1 Base Case

The base case scenario considers execution of the hypothetical project under the defined resource constraints of 10 units each for the five resource types. Once the resources are constrained, the problem becomes a RCPSP that may be solved using different heuristics by different project planning and simulation software. The deterministic solutions itself are different and hence the stochastic solutions could vary even more widely. For example, with constrained resources deterministic activity durations MS Project plan has a duration of 370 days while ExtendSim generated a project duration of 352 days. No specific resource assignment heuristics were used in either case. MS Project plan was generated using standard leveling order while resources were assigned to activities on first come first served basis in ExtendSim.

The constrained resources plan from MS Project was simulated using @Risk for the MCS option. In each iteration @Risk generates the stochastic activity durations and passes them back to MS Project to determine the project duration, cost, and other parameters. The outputs from MS Project are collected by @Risk and further processed to generate the histograms and other analyses.

The following details about @Risk and MS Project software are provided in the interest of repeatability of results by other researchers. In the basic version of @Risk, its interaction with MS Project does not include the ability to execute resource leveling with each iteration. Novice users may assume that the successive project plan iterations are honoring resource constraints and make incorrect decisions based on the generated results. The documentation for @Risk suggests that their standard engine instead of accelerated engine should be used "if resource constraints that affect activity duration or resource leveling are active during a simulation." However, even with the use of the standard engine, resources are overallocated in successive iterations in MS Project.

The ability to honor resource constraints in successive iterations of @Risk requires the use of VBA macros available from Palisade's technical support. The macros ensure that resource leveling is performed in MS Project at each iteration, the results of the iterations are captured, and leveling is then cleared in MS Project in preparation for next iteration, It should also be noted that even with "Level All" setting and no other date constraints specified, MS Project leveling doesn't always level all the resources across the entire project. RCPSP can be quite complex and perhaps some violations are accepted in MS Project solutions to achieve quick response times. Some have also shared the perspective that it may not be worthwhile to achieve the fully compliant solutions given the uncertainties in project environments. For the example used here, for about half the iterations MS Project had 3 tasks with overallocated resources out of 31 tasks. One has to set @Risk simulations to run in demo mode and closely watch the MS Project screen as it changes with successive iterations to notice the occurrence of resource overallocations. The results from @Risk for scenarios with constrained resources have been generated with these additional macros enabled.

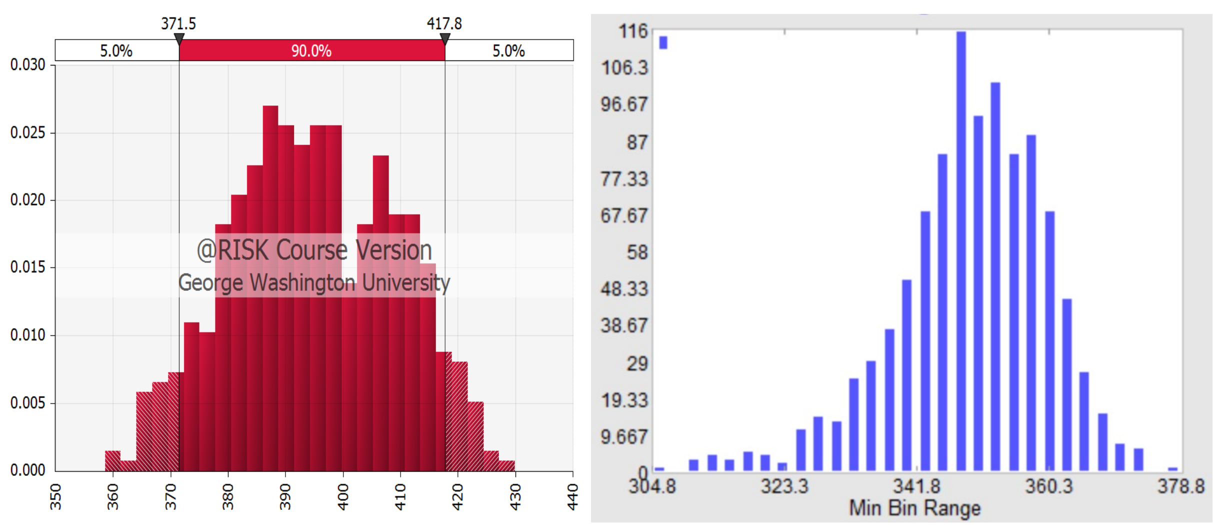
The DES option for the base case was executed in the ExtendSim model independent of the MS Project plan. Stochastic activity durations were used. The project duration PMFs for the base case are shown in Figure 4. Interestingly, even with MS Project allowing minor resource overallocations in successive iterations, MCS results show significantly higher durations than generated by DES as shown in Table 3.

A project manager will generally not commit to the objective of a 350-day PCT for this project given the results shown in Table 3. The DES results show that there is only about a 50% chance of completing the project in 350 days. The MCS results indicate a zero chance of achieving that goal.

Project managers in general would not simply accept the possibility of longer durations and prepare actions plans in case there are signs that project will run significantly late. The project manager would hence explore crashing scenarios given that there is some budget flexibility as mentioned in Section 3.2. The next subsection evaluates a crashing scenario with additional resources.

Table 3: Comparison of base case results.

Simulation Paradigm	Software Used	Project Duration in Working Days			
		Mean	5-percentile	50-percentile	95-percentile
MCS	@Risk	394.8	371.5	394.4	417.8
DES	ExtendSim	350.6	331.8	351.3	366.0



(a) (b)

Figure 4: Project duration histograms for base case from (a) MCS/@Risk and (b) DES/ExtendSim.

4.2 Crashing with Additional Resources

There could be multiple ways to use additional resources to crash the project, including using resources to crash activities on the critical path and using resources to allow parallel executions of activities. Optimization algorithms can be used to determine the best way to crash the project but it may require significant effort and expertise. In this scenario, the project manager evaluates the option of checking the progress of the project mid-way and bringing in additional resources if needed. Specifically, 2 additional units each of R1 through R5 are brought on to the project if activity H hasn't started by day 175 out of the 350-day duration. Activity H is a merge node for three separate paths with one of them being part of the critical path in the unconstrained scenario. In the DES model of the base case, activity H starts after day 175 about half the time and thus provides an early indication of the project heading towards a late completion.

The action plan was implemented in MS Project as a preplanned occurrence rather than conditional occurrence since that facility is not available in the software through the user interface. It may be possible using custom coding in VBA but few project managers have the necessary expertise. The resource calendars were modified to have 10 units each of the five resources types available for the first 175 days and 12 units after that. The resources were re-leveled using the MS Project leveling function after this change. The resulting plan had a deterministic duration of 356 days. Again, it should be noted that the solution will differ across different project planning software based on the heuristics used for the RCPSP. The implementation did suggest that a reduction of around 14 days may be possible with such a resource deployment action plan.

The policy of taking the action of adding resources to the project based on its progress in simulated time is difficult to implement in MCS using @Risk. @Risk does provide functions for adding and removing specific resources to/from specific activities but they can be activated using probabilities per the documentation. A feature for adding resources to the project team and allowing their assignment to different activities as needed was not found in @Risk. A project manager may consider simulating using @Risk the above MS Project plan with the mid-point addition of the resources to evaluate the possible reduction in project duration. This is not being recommended as an approach but the MCS runs have been carried to show the kind of results one can generate and the impact that may have on the decisions.

MCS results using @Risk based on a MS Project plan with a mid-point addition of resources are shown in Table 4 and Figure 5(a). The availability of additional resources clearly helps in reducing the project duration. The mean project duration reduced by about 25 days in MCS results compared to the base case. However, MCS results show only a 6% probability of project completion with 350 days! The poor performance of the project in MCS results appears to be primarily due to the resource leveling routine in MS Project. In each MCS run, random samples are drawn from defined distributions for each activity, and the updated project plan with the drawn activity durations is passed back to MS Project for resource leveling. The resulting plan with leveled resources is taken as the simulated execution and the associated project duration is recorded for the run in @Risk. There are alternate leveling order schemes available in MS Project, but the selected scheme applies to all MCS runs in a set rather than having the best one selected for each run.

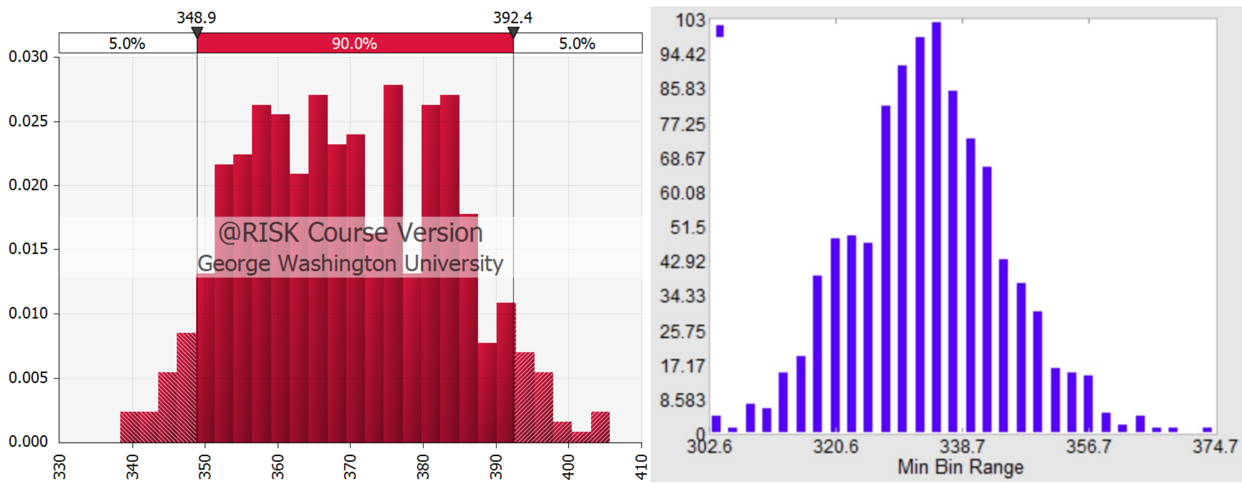
It is possible that some project managers may not realize the limitations of this setup of running MCS and consider these results as the final word. This may lead them to believe that the proposed action plan will not meet their needs and hence they might search for more expensive crashing solutions or worse yet abandon the project due to their interpretation that it will be very difficult to meet the desired PCT. Another perhaps equally bad possibility is that they may question the credibility of MCS as suggested by Williams (2004) and stop using the technique going forward.

The DES model developed using ExtendSim represented the action plan with the conditional trigger as desired. The project progress is checked by a flow unit generated on day 175 and resources are added if all the three predecessor paths of activity H haven't finished. DES model results are also shown in Table 4 and Figure 5(b). The mean project duration reduced by about 15 days in DES results compared to the base case.

It can be seen that with the action plan, the project has over a 90% probability of completing within the desired duration of 350 days. A project manager using DES results will hence be comfortable in committing to completing the project in 350 days as long as they have the flexibility in the budget to bring on the 2 units for each of the five resource types for the latter half of the project. Capture of the start times of activity H in the DES model indicated that the resource addition will be needed about 50% of the time. The senior management for the project manager's organization should generally be in support of such an action plan as it delays committing additional budget and has 50% chance of not being needed.

Table 4: Comparison of crashing scenario results.

Simulation Paradigm	Software Used	Project Duration in Working Days			
		Mean	5-percentile	50-percentile	95-percentile
MCS	@Risk	369.6	348.9	368.9	392.4
DES	ExtendSim	335.0	317.7	334.8	352.7



(a) (b)

Figure 5: Project duration histograms for crashing scenario from (a) MCS/@Risk and (b) DES/ExtendSim.

5 DISCUSSION

The results presented in the previous section show DES using a software such as ExtendSim has a clear advantage over MCS using a software such as @Risk for evaluating resource constrained project plans and action plans based on dynamic conditions during project executions. Project managers are cautioned that the advantages identified may be restricted to the narrow scope of comparison defined here and to the software products utilized. Most general-purpose DES software are expected to have the capabilities to model the scenarios in this study but the presence of associated features should be verified before acquiring the software for such applications. Also, while @Risk has some limitations specific to the crashing scenario, there may be other MCS software available that have the capability to model resource constrained project plans and the dynamic condition-based resource deployment. Even for @Risk the assessment should be considered as being limited to its academic version used in this study. The documentation for @Risk identifies advanced capabilities that are available in its industrial and professional versions. Though a specific capability meeting the needs of the scenarios was not identified in the documentation, it is possible that the industrial and professional versions may have features that can be combined to meet such needs.

The advantages offered by DES do come at the cost of expertise and effort required to develop the model for the project network. Building such a model and its variations for modeling alternative action plans in a general-purpose simulation software is not trivial. Many of the project managers that the author has interacted with over a decade are not familiar with DES. This unfamiliarity contributes to the low use of DES for supporting project management.

The use of MCS for supporting project management decisions is also not very common but it is relatively high compared to the use of DES for the purpose. Software products such as @Risk provide easy interfaces for using MCS. @Risk allows direct import of MS Project files and a friendly interface for defining stochastic activity durations and project risk factors. The ease of use of @Risk for MCS of project plans appears to have contributed to its higher use both in research and in practice.

DES may see increased use by project managers if there are software that facilitate building of project network models in a DES environment. While some DES tools are available for construction industry (see Shou et al. 2019 for a recent review), few commercial DES tools are available for domain independent project management. One such software is the Enterprise Portfolio Simulator (EPS) from ProModel Corporation. The EPS is designed specifically for modeling project portfolios using DES with all the data and rules specified using provided menus. The product has been designed with the philosophy of no coding required on the part of the user. It allows importing project plans from MS Project and similar to @Risk allows adding stochastic duration specifications of activities. EPS uses DES and hence it provides the capability of modeling individual and multiple project across a wide range of scenarios including constrained resources, activity crashing (that is, reducing activity durations with increased resources), fast tracking, and conditional routing. An attempt will be made in near future to evaluate the scenarios using EPS. Increased availability of similar DES tools for project management should help promote use of DES by project managers.

6 CONCLUSION

This paper reports on an initial study for comparing use of MCS and DES for project plan evaluations. The study showed a clear advantage of using DES over MCS for the narrow scope of this effort as pointed out in the preceding section. Project managers are cautioned to consider the results reported here as being applicable only within the defined scope and to the specific software used in this study. There is a need for follow-up studies to widen the scope of the comparison both in terms of project management objectives and software tools evaluated. Another potential direction is to include additional simulation paradigms such as system dynamics in such a comparison.

The results of this study should contribute to enhanced understanding of MCS and DES on the part of project managers. Such enhanced understanding in turn should help avoid misuse of simulation and lead to better project management decisions.

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