Project Management Model: Integrating Earned Schedule, Quality, and Risk in Earned Value Management

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***Abstract*—Earned Value Management (EVM) has been widely used as a project monitoring and control tool for projects due to its practical applications. This study integrates earned schedule, quality management, and risk management into earned value management to address the weaknesses and limitations of the traditional EVM and proposes a new project management model. The proposed model was tested in a sample bicycle project in order to validate its application. The proposed model was able to show how the quality problem affects the cost and schedule risk of a project with the quality performance metrics. The preventive actions made are also reflected in the risk indices as the project progresses. The proposed model also made the schedule delays more explicit and easy to understand since it shows the real time delay.**

Keywords-project management; earned value; earned schedule; quality management; risk management

I. INTRODUCTION

Basic project management involves achieving the requirements (time, budget, and scope) of the project in check. As the needs of the projects evolve over time, project management tools must also develop to address those changing needs. Earned Value Management (EVM) is a widely used management system to control and monitor a project. This tool compares the planned work (or the Planned Value), the actual accomplished work (or the Earned Value), and the cost of the accomplished work (or the Actual Cost) at a specific point in time. Project managers can track the variances in cost and schedule, both in terms of monetary units. Despite the obvious advantages of EVM, researchers have identified a number of limitations to EVM and have proposed several improvements and alternatives. Firstly, although EVM was able to monitor whether the project is on time or not, its schedule indicators become distorted in the as the project progresses [1]. The Schedule Variance (SV), the difference between EV and PV, at the end of any project will always be equal to zero in the traditional EVM. Consequently, the Schedule Performance Index (SPI), which is the ratio of EV and PV, will become 1 which indicates that the project is on time even if it is behind schedule. Moreover, the schedule indicators are measured in terms of monetary units, which does not really translate the real schedule delay for projects behind schedule.

In order to resolve this shortcoming of EVM, [1] proposed the use of "Earned Schedule" (ES) concept which uses time units for the schedule indicators instead of monetary units. In this concept, the schedule variance is derived from difference between the actual time and the time the current EV was supposed to be earned based on the PV curve. The schedule indicators in the Earned Schedule concept was proven to behave appropriately throughout the entire project duration [2], [3]. Furthermore, it was found in similar studies that ES provides an advanced analytical approach that measures performance in units of time and that indicators supply a predictive status ability for schedule which are time-based metrics, thus enhance the integrated schedule analysis and traditional EVM [3].

The cost management aspect of EVM is also lacking in terms of showing the different types of costs incurred for the project. Initially, the estimated costs of resources needed to execute the project are identified in EVM. However, aside from these costs, there are also other costs the may be incurred such as cost of quality (CoQ) and risk-related costs which are not explicitly measured in EVM, making it inadequate in the area of quality management and risk management. Although CoQ may already be accounted in the cost metrics of EVM, it does not explicitly show these costs, thus it cannot show how quality affects the total cost of the project. Aside from the costs, EVM does not show how quality can affect the schedule as well. Overall, EVM has no quality related metrics, thus it cannot measure quality objectively [4]. By means of EVM, the project can be on time and under budget but still might be low quality if it does not satisfy customer requirements. If a finished deliverable in a certain project did not meet the quality requirements, it needs to be reworked before it moves on to the next activity it is preceding. Thus, an additional cost (Rework Cost) and time will be needed for the rework, making the actual project duration longer.

Furthermore, in other cases, quality problems only become visible in the last phase of the project. In some types of projects such software development projects, the need for rework for a particular milestone mostly occurs after several milestones have passed already [5]. The lack of quality leads to cost of non-conformance and may contain internal and external costs which includes rework costs. These may be caused by errors in the project development or inefficiencies in the project which leads to the customer not being satisfied. Thus, as the actual project costs increases, the total failure cost decreases [6].Quality management has been proven to contribute significant cost savings in projects specifically in construction projects [7]. The studies of [8], [9], [10], [11], and [5] attempted to contribute in resolving this limitation of

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EVM. These studies show how quality related costs affects the project cost status. However, they did not consider the possibility of having quality issues in activities that are not included in the critical path. If that is the case, then reworking that activity would not delay the project, as long as it will not exceed the critical path's time.

Risk-related costs on the other hand are the costs that would be incurred if the risks in the project materialized. The most common project risks are cost risk, schedule risk, and performance risk. In EVM, the only risk metric identified is the Variance at Completion (VAC) assumes that the current cost performance of the project will be the same throughout the remaining work. However, this approach does not capture other risk factors, thus making it not very reliable. VAC may report a cost overrun which is not alarming for the project manager but in reality, the cost overrun is much serious than what is reported. Moreover, it also does not account the increased cost due to schedule delays. [9], [12]–[14] are some of the authors which have integrated risk management into EVM.

The existing studies in the literature have resolved the limitations of the traditional EVM individually. The study of [11] used earned schedule in his study of integrating risk management into EVM. [11] proposed a process framework for integrating project quality and risk management, together with another concept called integration management into EVM. Integrating all the three concepts into EVM would enable it to monitor all the project management elements with more accuracy. However, there is no study yet in the literature which integrates all these concepts into EVM simultaneously.

The objective of this study is to integrate earned schedule, quality management, and risk management in earned value management with a model that can be easily used by project managers. With this goal in mind, the availability and accessibility of the additional information required in the proposed model was also taken into consideration. The proposed model aims to enable the project managers to track project progress and performance in terms of cost, schedule, and quality, as well as determine the associated risk given the current performance.

II. Model Development

The model being developed in this study is an extension to the traditional EVM which aims to integrate the concepts previously added in the EVM such as the earned schedule, quality management, and risk management. These concepts directly address the limitations and weaknesses of the traditional EVM.

Moreover, in the development of the proposed model, the researchers also take into consideration the availability or accessibility of the additional information needed to compute the new performance indicators. The added performance indicators and the required inputs in the proposed model are discussed as follows.

A. Schedule Performance Metrics

In the proposed model, the schedule indicators that will be used are adopted from the Earned Schedule concept by [2]. This concept was proven to be very useful in reporting the real performance of the project in terms of schedule. The elements of Earned Schedule included in the model are discussed as follows.

1) Planned duration (PD)

Planned Duration is defined as the total time needed to finish the entire project based on the work breakdown structure. This is the expected total duration given the amount of time needed to complete each milestone.

2) Actual time (AT)

The Actual Time is the total time the project has been ongoing.

3) Earned schedule (ES)

The project's Earned Schedule tells how the project progresses in terms of schedule. It projects the current cumulative earned value to the planned value curve and determine the time when the current earned value is supposed to be earned. It can be computed by using the formula below.

$$ES = C + I \tag{1}$$

Where
C = number of complete periods
I = incomplete portion
= (EV-PVC)/(PVC+1-PVC)

The calculation of ES is just a simple linear interpolation of the amount of schedule to credit for the month partially completed [2].

4) Schedule variance (SVt)

The Schedule Variance in the earned schedule concept by [2] shows how much additional time is spent for the work completed compared to the time allocated to it. It can be computed using the formula below.

$$SVt = ES - AT \tag{2}$$

Where
ES = Earned Schedule
AT = Actual Time

If the SVt is positive, it means that the project is ahead of schedule. The amount of time spent on the work performed is less than what it expected. If the SVt is negative, it means that the project is behind the schedule. The project is experiencing delays on the schedule. Lastly, if the SVt is equal to zero, then the project is on schedule.

5) Schedule performance index (SPIt)

The Schedule Performance Index shows the rate how much the project is progressing based on the planned period for each time period of the actual time.

$$SPIt = ES / AT \tag{3}$$

B. Quality Performance Metrics

The quality performance indicators measure the ability of the project to deliver quality requirements throughout the project execution. Some of the elements here were adopted from the study of [11].

1) Quality requirements (QR)

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Quality requirements are the specifications set for the output of each milestone of the project. A milestone may have a single or multiple quality requirements. These requirements should be planned and set by the stakeholders at the planning phase. These specifications should be clear so that scope creep will also be avoided.

The output of each milestone will be subjected to its corresponding QRs. The project manager has to rate the output against each QR with 1 or 0 - 1 indicating that it has passed the QR or 0 otherwise.

2) Quality index number (QIN)

QIN is only the average of the QR rating for a certain milestone output. It indicates how much of the QR are met.

3) Quality earned value (QEV)

QEV is the portion of the earned value which passed the quality requirements. The quality can only be measured after the milestone has been done, thus the QEV can only be computed by then. While the milestone is in progress, the QEV is assumed to be equal to the EV.

$$QEV = EV \text{ of finished milestone} * QIN \tag{4}$$

It is important to take note, especially for projects with non-critical path tasks, that the EV being used in the computation of the QEV is the EV of the milestone, not the total EV in a particular period.

4) Quality variance (QV)

Quality variance represents the portion of the earned value that needs to be reworked. It can be computed using the formula below.

$$QV = QEV - EV \tag{5}$$

5) Quality performance index (QPI)

Similar to the concept of the performance indices in traditional EVM, this performance index indicates the efficiency of the project in meeting the quality requirements. QPI represents the ratio of the tasks done right for the first time considering all the work and rework till that time [11].

$$QPI = QEV/EV \tag{6}$$

6) Estimated rework cost (ERC)

The estimated rework cost represents the planned added cost of the corrective action or rework that must be done to eliminate the non-conformance [6]. This input is needed for the calculation of the risk involved in quality problems.

7) Estimated rework time impact (ERT)

This is the overall project schedule delay attributed to the rework time. If the milestone that needs rework is not included in the critical path, it would not affect the time variance at completion provided that there is enough slack time to cover the rework time. Therefore, the rework impact is 0. Otherwise, the rework time impact is the same as the rework time.

C. Risk Performance Metrics

In every project, there is a risk of exceeding the budget and/or not finishing on time. The factors contributing to these risks include the risk of not meeting the quality requirements which therefore results to rework, and other risks that has been identified in the planning phase. The assumption for the risk of the project is that past performance affects the future performance.

1) Rework Cost Impact Rate (RCi)

$$RCi = \text{Cost Impact}/AC \tag{7}$$

where

Cost Impact = cumulative value of actual rework cost + ERC

2) Rework Time Impact Rate (RTi)

$$RTi = \text{Time Impact}/AT \tag{8}$$

where

Time Impact = cumulative value of actual rework time impact + ERT

3) Cost risk value (CRV)

This measures how much will the project cost variance be, given the current status of the project. It assumes that the amount of rework cost in the current time will also be proportional with the amount of rework cost in the remaining tasks.

$$CRV = BAC - (\text{Quality related cost risk} + \text{Estimated cost at completion} + ORc) \tag{9}$$

Where

Estimated cost at completion = AC + [(BAC - EV)/CPI(risk)]

Quality related cost risk = [(BAC - EV)/CPI(risk)] * RCi

CPI(risk) = EV/(AC + ERC)

ORc = Cost impact of other risks identified at the planning phase which are not quality-related (Probability of occurring * Cost impact)

4) Schedule risk value (SRV)

This measures the total schedule variance of the project given the current performance. SRV can be calculated with the formula below.

$$SRV = PD - (\text{Quality related schedule risk} + \text{Estimated time at completion} + ORt) \tag{10}$$

where

Estimated time at completion = AT + [(PD - ES)/SPI(risk)]

Quality related schedule risk = [(PD - ES)/SPI(risk)] * RTi

SPI(risk) = ES/(AT + ERT)

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ORt = Schedule impact of other risks identified at the planning phase which are not quality-related (Probability of occurring * Time impact)

5) Cost risk index (CRI)

Measures how critical the cost risk is with respect to the planned cost of the project.

$$CRI = CRV / BAC \tag{11}$$

6) Schedule risk index (SRI)

Measures how critical the schedule risk is with respect to the planned duration of the project.

$$SRI = SRV / PD \tag{12}$$

III. Computational Experiments

The methodology studied in this study is basically a scenario analysis that compares performance metrics resulting from the traditional project management approach against metrics resulting from the recommended approach which considers earned schedule, risk, and quality. In this simulation, we had considered the construction of a bicycle (Figure 1).

A. Using Traditional EVM

After inputting the WBS, resources, actual costs, and rate of completion, the different metrics (as shown in Table I were computed using the traditional EVM methodology. Using the data output, the PV, EV, and AC were graphed in order to have an analysis regarding the project at a certain status date which, in this case, was period 12. In the EVM methodology, if actual cost (AC) is higher than earned value (EV), then the project is over budget.

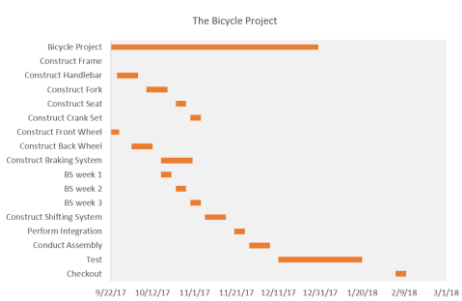

Figure 1. Gantt chart of bicycle project.

Moreover, if planned value (PV) is higher than earned value (EV), then the project is behind schedule. As seen in figure 2, all throughout the twelve-week period, the project is over budget since the AC is higher compared to that of the EV. Moreover, it is can be seen in Table I that the CPI in all 12 periods is greater than 1 further showing proof of over budgeting. In terms of the schedule, it can be seen that the project is delayed from periods 4 onwards as the PV line is higher than the EV line as shown in figure 2. In Table I, a slight delay can be observed in period 3 which has an SPI less than 1. As previously discussed, the schedule indicators of the traditional EVM are measured through monetary units instead of duration. Thus, the real delay may not be captured accurately.The metrics considered in this case are in terms of time and cost in order to compute the EV, PV, and AC. Indicators such as the SPI and CPI serve as signals to which a project is under-, within- or over-budget and behind, on, or ahead of schedule, respectively. These indicators do not necessarily indicate whether the project is successful and had met desired specifications or quality. There may be necessary rework, thus creating additional tasks, costs, and duration. In the next section, the same case will be evaluated using the recommended methodology which integrates the concepts of Earned Schedule, Risk Management, and Quality Management into EVM.

B. Using the Proposed EVM Model

In testing the proposed model, two scenarios are made with the existing project. In the first scenario, the proposed model will be used to analyze the current situation. Meaning, the project is already in progress, specifically in the 12th week as can be seen in figure 3. The preventive features of the model will not be seen in the first scenario but it can still present the actual status of the project considering quality and risk. In the second scenario, the proposed model will be used as the project monitoring tool from the start of the project up to the current status date.

1) Using the proposed model to analyze the current project status

In this scenario, it is assumed that no rework has been done to correct the quality non-conformance in the project since the project managers have not seen the quality problem yet.

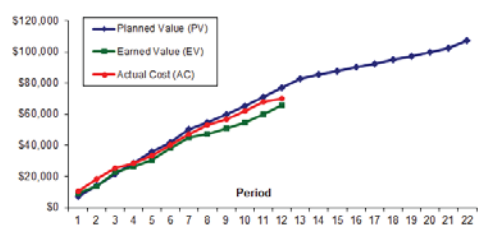

Figure 2. Traditional EVM graph.

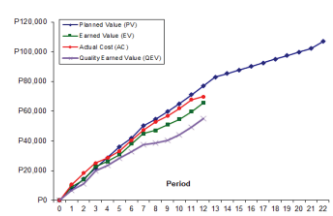

Figure 3. Proposed graphical analysis for scenario 1.

Applying the proposed model in this project reveals the quality non-conformance of the work performed as shown in figure 3. It shows that the output of the work performed is

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not meeting the quality requirements, thus a lot of reworking is needed.

TABLE I. EVM METRICS

	Period (Weeks)											
EVM Metrics	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Total Budgeted Cost (Php)	7,200.00	7,200.00	7,200.00	7,200.00	7,200.00	5,920.00	8,320.00	4,320.00	5,200.00	5,200.00	6,000.00	6,000.00
Cumulative Planned Value (PV) (Php)	7,200.00	14,400.00	21,600.00	28,800.00	36,000.00	41,920.00	50,240.00	54,560.00	59,760.00	64,960.00	70,960.00	76,960.00
Cumulative Actual Cost (AC) (Php)	6,166.67	8,750.00	12,125.00	15,600.00	20,200.00	27,400.00	34,200.00	39,800.00	43,800.00	47,800.00	51,800.00	52,400.00
Cumulative Earned Value (EV) (Php)	9,199.48	13,800.00	22,600.00	26,200.00	30,800.00	38,000.00	44,752.00	47,040.00	50,960.00	54,560.00	59,760.00	65,560.00
Cost Variance (CV = EV - AC) (Php)	3,032.81	5,050.00	10,475.00	10,600.00	10,600.00	10,600.00	10,552.00	7,240.00	7,160.00	6,760.00	7,960.00	13,160.00
Schedule Variance (SV = EV - PV)	1999.48	-600	1000	-2600	-5200	-3920	-5488	-7520	-8800	-10400	-11200	-11400
Cost Performance Index (CPI = EV/AC)	1.49	1.58	1.86	1.68	1.52	1.39	1.31	1.18	1.16	1.14	1.15	1.25
Schedule Performance Index (SPI = EV/PV)	1.28	0.96	1.05	0.91	0.86	0.91	0.89	0.86	0.85	0.84	0.84	0.85
Estimated Cost at Completion (EAC) (Php)	71,698.26	67,818.84	57,384.51	63,686.11	70,149.09	77,123.79	81,740.08	90,497.62	91,931.87	93,707.62	92,712.99	85,489.69
Estimated Time at Completion (ETC)	86.09	114.78	105.13	120.92	128.57	121.35	123.49	127.59	127.00	130.97	130.62	129.13

TABLE II. RISK IDENTIFICATION

Task Name	Probability	Cost Impact	Schedule Impact
Construct Crank Set	0.5	5000	2 weeks
BS week 3	0.8	5000	2 weeks

Table II shows the milestones which did not meet their respective quality requirements (QIN < 1). The rework index (RI) is the part of the task which did not meet the quality requirements or in other words, needs rework. It is calculated by subtracting the QPI to 1. The rework cost is estimated by multiplying the RI by the actual cost of the milestone. In this case, it is assumed that the cost of rework is proportional to the actual cost of the milestone.

TABLE III. MILESTONES THAT NEED REWORK

Task Name	AC (Php)	AT (Week)	QIN	RI	Estimated Rework Cost (Php)	Estimated Rework Time (Week)	Estimated Delay Impact (Week)
Construct Frame	4500	1	0.33	0.67	3000	0.67	0
Construct Seat	4400	1	0.50	0.50	2200	0.50	0
Construct Back Wheel	10400	3	0.75	0.25	2600	0.75	0.75
Construct Braking System 1	4000	2	0.70	0.30	1200	0.60	0.60
Construct Braking System 2	4000	1	0.50	0.50	2000	0.50	0.50
TOTAL					11000	3.0167	1.85 weeks

The estimated rework time is not same as the estimated delay impact since there are tasks which are not included in the critical path. In this case, only those in the critical path affects the project schedule delay since there is enough slack time for non-critical path task to cover to the rework time.

The proposed EVM analysis reveals that the project has a risk of exceeding the budget by Php 21,905.00 and a schedule delay of 10.35 weeks. These values were not captured in the traditional EVM since it does not record the impact of rework.

2) Using proposed model from the start of the project

In this scenario, the full potential of the proposed model can be examined. The monitoring capability of the proposed model would be shown in this sample application. The proposed model requires the identification of risks and specification of the quality requirements at the planning phase of the project. The risks identified are given in table III. Quality requirements will be the same as the previous scenario.

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The proposed EVM analysis in the first week shows that the project is over budget but ahead of schedule. However, the QPI indicates that the work performed only passed 71% of the quality requirements which means rework must be done. This allows the project manager to perform immediate corrective action, right after the milestone has been completed. This reduces the further quality problem which may affect the other milestones dependent on the current milestone. The estimated rework cost and time impact is captured in the risk indices, not in the actual cost and actual time. Only the cost risk index of the project is very critical (above 50%) and not the schedule risk since the milestone that needs rework is not in the critical path. The project is expected to have a cost overrun of about 88% (or Php 94,489.90) of the budget at completion. This indicates that if the project team continue to perform the way they do during week 1, it will result to a huge problem in the future.

Figure 3 shows the proposed EVM graph up to week 12. In the second week, the QEV is in par with EV which means that the rework is done and the quality requirements are already met. The actual rework cost is only Php 2000 which resulted to lower CRI. The CPI also decreased due to the added cost of rework. On the other hand, the actual rework time is 1 week which is greater than the estimated rework time. But since the milestone involved is not part of the critical path, it did not have any effect on the delay of the whole project. The SRI became lower in the 2nd week because of the lower SPIt, which is 1. Having an SPIt of 1 is generally good - it indicates that the project is progress at a rate it was planned. However, since there is an identified risk, having an SPIt of 1 throughout the remaining work would still make the project delayed.

A preventive action for the identified risks was done in week 3 which contributed to the decrease in the risk indices. The improvement in CRI is minimal however due to the additional cost incurred for the preventive action, which further increased the cost variance. The earned value was very close to the planned value until week 5 as shown in figure 3. At week 6, the EV started to deviate from the PV because of the rework. The rework this time occurred in a milestone which is included in the critical path, therefore it resulted to a significant increase in the SRI. During week 6, the rework was performed which caused the SPIt to decrease. The SRI also decreased since the actual rework time is less than the estimated time. Another milestone in the critical path did not pass the quality requirements during week 7. Since the rework will affect the critical path, the SRI increased significantly from -0.256 to -0.471 which is equal to 10.351-week project delay. In week 9, another preventive action was done to mitigate the probability of the identified risks. This action completely eliminated the identified risks which should result to better risk indices. However, the CRI increased because of the additional cost of the preventive action and rework done during week 9.

The graph of the risk indices as shown in figure 4 could be useful in evaluating the effectiveness of risk-mitigating actions done by the project team. The preventive actions can be in terms of improving the cost and schedule performance by motivating the team and such, in terms of improving the quality of work therefore reducing the cost and schedule impact of rework, and also in terms of planned actions in order to reduce the impact of the identified risks.

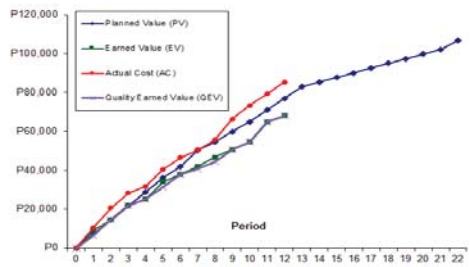

Figure 4. Graphical analysis using proposed model.

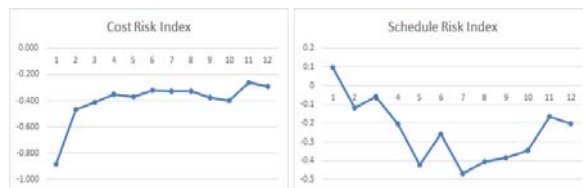

Figure 5. Risk index graph.

IV. Conclusions

EVM has been widely used as a project monitoring and control tool for projects due to its practical applications. The literature has discussed and addressed its weaknesses and limitations in capturing the elements of project management. As an attempt to integrate the promising extensions present in the literature, this study proposed an EVM model that captures the cost, schedule, quality, and risk elements of project management.

The proposed model was tested in a sample bicycle project in order to validate its application. The proposed model is able to show how the project is progressing in terms of cost, schedule, and quality, as well as show the risks involved. The quality performance metrics are able to show how the quality problem affects the cost and schedule risk of the project. The preventive actions made are also reflected in the risk indices as the project progresses. The Earned Schedule concept made the schedule delays more explicit and easy to understand since it shows the real time delay.

In addition, the proposed model is useful in revealing hidden costs such as rework costs and risk costs and integrates them into project management and performance management giving managers more visibility. In contrast, the traditional EVM is not capable of revealing these costs and thus, understating the project's progress. Moreover, it measures risk and quality status of the project at a given time in addition to schedule and cost. It can also provide managers more accurate progress at any given time and can be used to estimate future progress more realistically.

For further study, it is recommended that the effectiveness of the model be tested in real project application of various types. Through this, the proposed model can be further developed to cater to the needs of project managers in practice. The effectiveness and

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efficiency of the risk mitigation actions can also be explored in order to improve the risk aspect of the model.

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