# Research on the Impact of Project Network Topology on Project Control

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## Abstract

The timely completion of the project is an important factor in the success of the project. However, the project often exceeds its predetermined deadline, resulting in delay in project delivery and increase in the total cost of the project. In order to improve the completion rate of the project on time, it is necessary to carry out timely monitoring during the progress of the project so that the project can be adjusted in time. This article through Monte Carlo simulation of different network topology projects, using the earned value method to monitor different monitoring points, the simulation results are analyzed, the results show that different network topology projects need to control the distribution of different stages of the project To save the manager's energy and improve the control efficiency.

## Keywords

Project Network Topology, Project Control, Earned Value Management, Monte Carlo Simulation

## 1. Introduction

The Project Management Institute (PMI) defines a project as a temporary work to create a unique product or service (PMBOK, 2004)[1]. The project has a definite goal and a definite starting point and end point, and it needs to be completed within a limited time and within a limited time with limited resources. Usually, a detailed schedule will be prepared before starting the project execution. The plan describes the dates of the start and end of activities, the number of resources used for various activities, the budget allocated to support these resources, and the technical and operational characteristics of the deliverables that each activity will produce. Although the timely completion of the project is an important factor in the success of the project, the completion of the project is still very common. According to the global PMI survey, only 49% of projects can be completed on time (PMI, 2016)[2]. In most cases, due to the numerous uncertainties of the project, such as delays caused by suppliers, changes in raw material prices, changes in customer requirements, and the occurrence of unexpected conditions such as weather, actual project schedule execution often deviates from the plan. Project control is a response mechanism designed to help managers respond to the impact of these unexpected factors on project schedules. The goal of project control is to measure the actual implementation of the project, compare it with the plan, analyze the causes of the deviation, and formulate measures to correct the deviation so that the project can get back on track.

Various issues in the project control phase have been discussed in the existing literature: Partovi and Burton (1993) compared five control time strategies by computer simulation: equal time intervals, terminal load, preload, complete random monitoring, and no monitoring and The effectiveness of control. The results show that, although there is no significant difference in the workload of each strategy, the use of terminal policies has the best effect in preventing overtime[3]. Tareghian (2009) et al. used simulation optimization to find the optimal number of control points and their time, and concluded that the number of control points has an upper bound. It also pointed out that it is more advantageous to put the control point in the early stage of the project duration. This may be due to differences in the network topology used in the study[4]. Raz and Erel (2000) determine the optimal time for the project control point based on the maximum amount of information generated by the control point. They developed an optimal solution based on dynamic programming and determined the time for each control point for a given number of control points[5]. Golenko-Ginzburg and Laslo (2001) in order to minimize the number of control points (maximizing the time span between two adjacent control points) when dealing with production control problems in processing semi-automatic production systems, at any conventional control point, Determine the planned production volume, planned scope, actual cumulative production observed at the control point, and the opportunity constraints to determine the time for the next control point[6]. Narjes Sabeghi (2015) and others used the adaptive method of facility location model (FLM) to find the optimal time of project control point from the perspective of project control dynamics[7]. Ji Zhongkai et al. (2015) conducted a comparative study of the key indicators of the process: key process probability, process criticality, and significance coefficient, and proposed a new index that measures process criticality—process importance and uses this indicator to assist project managers in monitoring. Project[8]. Zhang Lihui et al. (2013) used a delay step function to fit the various types of process in the project to determine the control route in a repetitive project, and proposed a more flexible control method that meets the actual engineering requirements[9].

The literature made a lot of discussion on the timing of the best selection of project control points, the prediction of project duration, the generation of monitoring and warning signals, and the implementation of corrective measures. This article focuses on the impact of project network topology on project control, through Monte Carlo simulation of projects with different network topologies, using earned value method to monitor, and analyze the resulting warning results to obtain different network topology The impact of the project on control has a certain guiding significance when the project manager controls the project.Organization of the Text.

## 2. Related Theory Introduction

Earned Value Management (EVM), which originated in the United States Department of Defense in the 1960s, is a well-known method of monitoring project progress and evaluating program deviations. Instead of monitoring the progress of each activity individually, EVM aggregates the progress information at a higher WBS level. EVM uses three key metrics to measure the progress of the project, namely, Plan Value (PV), Earned Value (EV) and Actual Cost (AC).

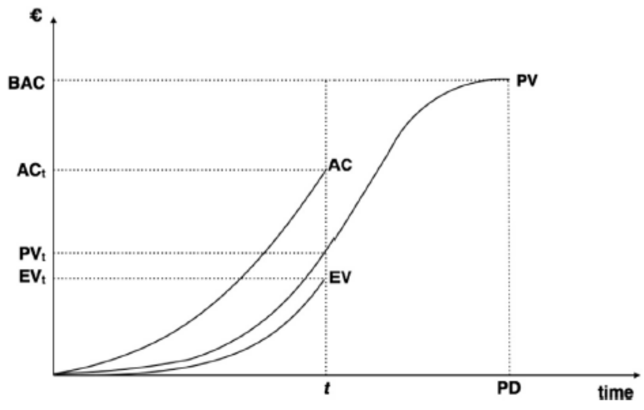


Fig. 1. PV curve of a project

The PV curve of the project is shown in FIG. The curve depicts the cumulative value for each period planned during the project life cycle, as determined during the project planning phase. In addition, EVs and ACs are periodically measured during project implementation to determine the progress of the project. Figure 1 depicts the EV and AC curves up to time t, representing the actual earned value up to time t and the cost incurred, respectively. Therefore, when the EV at the time t is lower than the PV at that time, it indicates that the progress of the project is slow and the delay occurs. Similarly, when the actual cost AC at time t is higher than the PV, it indicates that the project is experiencing budget overruns. In addition, based on these key indicators, four different indicators were constructed to assess the project schedule performance and cost performance to determine the actual progress and plan deviation. The four differences are: project cost deviation CV, CV = EV-AC; project cost difference index CPI, CPI = EV/AC; project schedule deviation SV, SV = EV-PV; project schedule difference index SPI, SPI = EV /PV. These indicators comprehensively reflect the implementation of the project. CV>0 or CPI>1 indicates project cost savings, CV=0 or CPI=1 indicates that the project cost is in line with budget, CV<0 or CPI<1 indicates project cost overrun; SV>0 Or SPI>1 indicates that the project progress is ahead of schedule, SV=0 or SPI=1 indicates that the project schedule is in line with the plan, and SV<0 or SPI<1 indicates that the project schedule is delayed.

Earned value management considers project scope, schedule, cost, etc. The resulting benchmark of performance measurement provides a method for project managers to evaluate and measure project performance and progress. This article uses the method of earned value management to monitor the project and use progress performance indicators. SPI monitors the progress of the progress. If the SPI value is less than 1, it means that the delay in this phase may cause the project to fail to be completed on schedule and generate an alarm signal, providing information for managers to adjust the schedule in a timely manner.

### 2.1 Project Network Topology

Vanhoucke (2010)[10] connected the network topology information of this data set to the monitoring project time performance generation test using a set of 900 virtual projects generated by the project generator RanGen[11,12] A serial/parallel (SP) indicator was proposed. The topology of the project network uses SP indicators to measure the closeness of the project to a complete serial or parallel project, and takes values in the interval [0,1]. The SP calculation method is as follows:

$$SP=(m-1)/(n-1).$$

Where m is the number of items on the longest link of the network and n is the total number of activities in the network. A project network with a low SP value (for example, the number of items on the shortest link is 1) is close to a completely parallel network (SP = 0), and a project network with a high SP (for example, the longest link is the entire project network) Closer to full serial network (SP=1).

Different projects in different network topologies have different influences on the entire project duration. As shown in Figure 2, there are three different network topologies P1, P2, and P3. Their SP values are 1, 0.5, and 0.3, respectively, and they have different network topologies. Structure, project process i has a different degree of influence on the entire project duration.

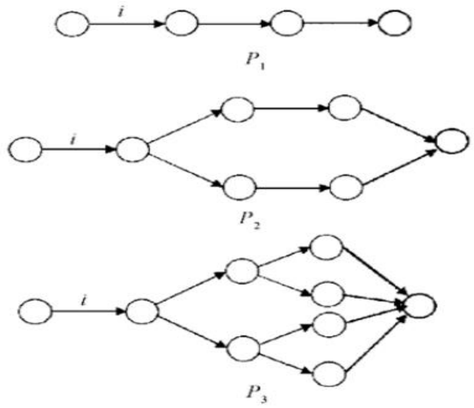


Fig. 2. Network diagram for projects P1, P2, and P3

In the actual project, the planning stage can determine the longest link of the project, that is, the critical route, so the SP value of the project is determined, and basically it will not change due to unexpected factors. This article takes the project of different network topology as the research object, studies its influence on the project control, and has certain significance for guiding the project control.

## 3. Research Methods and Experimental Design

### 3.1 Data Generation

In order to study the influence of different project network topologies on project control, ten projects were created in this paper. The project's SP value is (1, 0.9, 0.8...0.1). Each project contains ten activities. The duration of the activities is from 4 to For the 90-day distribution, the value generated at the completion of each activity is distributed within 60 to 900. For the accuracy of the experiment, it is assumed that the estimated time and cost of each process in the project are independent of each other, and the key route of each project during the simulation is simulated. Without change, this study only studied the network topology structure and the impact mechanism between schedules, and did not involve costs.

### 3.2 Monte Carlo Simulation

For the ten different SP value items generated in this paper, 1000 Monte Carlo simulations were performed for each of the ten activities. In this paper, the variation of activity duration is modeled by the probability density function of generalized β distribution. The generalized beta function has long been associated with PERT estimates in project management (McBride and McClelland, 1967)[13] because they can accurately model the behavior of the system's stochastic input process (Kuhl, Lada, Steiger, Wagner, & Wilson, 2007)[14]. AbouRizk, Halpin, and Wilson (1994)[15] proposed an approximate method that fits the β distribution with historical data or subjective estimates in the case of uncertainties characterized by long tails. Is often described. This approximation yields an estimate of the beta shape parameter from a single auxiliary parameter, calculated from a PERT-type three-point estimate. In Vanhoucke (2011)[16], these approximations have been used to test the performance of the EVM time prediction method on large fictitious data sets. This paper proposes to use the parameter vector $\omega$ = a, b, m, $\mu$, where a, b, m, $\mu$ denote the minimum value, maximum value, mode and mean value of process time estimation respectively. In this paper, m = 1 is selected for simulation. When Monte Carlo is used for simulation, the parameters are calculated according to the PERT method: $\mu=(a+4b+c)/6$, $\sigma=(c-a)/6$. During the experiment, in order to ensure the effectiveness of the experiment, 1000 Monte Carlo simulations were performed for each process in each project.

### 3.3 Monte Carlo Simulation

During project monitoring, the impact on project control is determined by the number of correct or incorrect warning signals generated during the project life cycle. For deferred projects, as each delayed signal will cause the administrator to take corrective actions to compensate for the progress of the project, the correct warning signal should be generated as much as possible during project monitoring. On the contrary, projects that are completed in time should generate warning signals as little as possible, because these signals can cause unnecessary efforts by managers. In order to facilitate the evaluation, this article draws on the study of Martens A (2017)[17] and introduces four tracking cycle level indicators. Two of these indicators consider correct and incorrect signals, namely signal density and signal redundancy. The other two indicators take into account the correct and incorrect signals, namely signal efficiency and signal reliability.

The signal density reflects the average semaphore generated during the life cycle of the deferred project and is defined as follows:

Signal Density = number of delayed projects/delayed items

Signal redundancy indicates the average amount of warning signals generated during the project lifecycle of a timely completion project, defined as follows:

Signal Redundancy = Number of Signals/Timely Items Generated by a Timely Project

The signal efficiency combines the correct and false warning signals and indicates the relative number of correct warning signals generated by the monitoring. It is defined as follows:

Signal efficiency = number of signals / total number of signals generated by delay items

Signal reliability indicates the relative number of error warning signals generated during monitoring and is defined as follows:

Signal reliability = number of signals not generated in a timely project / no signal generation

In addition to the above four indicators, this article added an indicator to measure the relationship between the number of project alarms and the number of project delays. The definition of signal validity is:

Signal validity = project alarms/project delays

### 3.4 Progress Tracking

Monitor the progress of the imaginary execution of the simulated project. Monitoring time selection measures project progress when the project reaches 10%, 20%, ..., 100% completion. Therefore, each fictitious item is executed during K = 10 examinations, at k = {1, 2, ..., 10} × ΔPC, ΔPC = 10%. The EVM data was measured at each monitoring time point, and the SPI values were calculated. Subsequently, these data were compared to obtain four schedule performance indicators in Section 3.3.

## 4. Results Analysis

In this paper, 10*10*1000 simulations were carried out. Each project was monitored 10 times. Each monitoring generated the value of Earned Value Indicator (SPI). The result of each monitoring was compared with the simulated project results. Data, the data analysis to get the value of various indicators to draw conclusions. The following takes the simulation result of SP=0.5 as an example to illustrate the analysis process. Table 1 shows the statistical results of the data generated by the simulation of SP=0.5 project:

Table 1. SP=0.5 Project Statistics Results

| Monitoring time / Statistical indicators | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Delayed and correct warning | 261 | 320 | 308 | 306 | 305 | 299 | 374 | 340 | 359 | 404 |
| Delayed and error warning | 143 | 84 | 96 | 98 | 99 | 105 | 30 | 64 | 45 | 0 |
| Timely and correct warning | 461 | 441 | 428 | 422 | 430 | 417 | 414 | 506 | 537 | 596 |
| Timely and error warning | 135 | 155 | 168 | 174 | 166 | 179 | 182 | 90 | 59 | 0 |

By comparing the SP=0.5 project simulation experimental data, there are 414 simulations in the 1000 simulations of the project are delayed. The number of SPI values less than 1 in 10 monitoring is: 422,427,514,512,487,488 492,441,448,414. According to the index calculation formula in 3.3, the results of each index of the project with SP=0.5 are shown in Table 2:

Table 2. SP=0.5 Item Index Calculation Results

| Monitoring time / Index calculation | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Signal density | 0. 64604 | 0. 792079 | 0. 762376 | 0. 757426 | 0. 75495 | 0. 740099 | 0. 925743 | 0. 841584 | 0. 888614 | 1 |
| Signal redundancy | 0. 77349 | 0. 739933 | 0. 718121 | 0. 708054 | 0. 721477 | 0. 699664 | 0. 694631 | 0. 848993 | 0. 901007 | 1 |
| Signal efficiency | 0. 659091 | 0. 673684 | 0. 647059 | 0. 6375 | 0. 647558 | 0. 625523 | 0. 672662 | 0. 790698 | 0. 858852 | 1 |
| Signal reliability | 0. 22351 | 0. 295238 | 0. 320611 | 0. 334615 | 0. 3138 | 0. 342912 | 0. 40991 | 0. 157895 | 0. 101375 | 0 |
| Signal validity | 1. 080882 | 1. 04902 | 1. 034314 | 1. 053922 | 1. 022059 | 1. 014706 | 1. 240196 | 1. 316176 | 1. 460784 | 0 |

This article will deal with the experimental data to draw the following conclusions:

1) The signal density reflects the average semaphore generated during the extended project life cycle and also reflects the accuracy of the signal to some extent. The calculation of the experimental data is summarized in Figure 3. From this figure, the signal density closer to the end of the project as the monitoring time is closer to 1 is closer to 1, because the uncertainty of the project is smaller as the project is completed. The closer the alarm signal is to the real situation. At the same time, the signal density of the items with different SP values is also different. The SP signal density between 0 and 0.5 varies from 60% to 80% in the project, and the SP signal is between 0.6 and 1. The density varies from 30% to 50% of the project. The number of alarm signals generated by the project with different SP values is different at different stages of the project, and the range of change is also different. It is necessary for the project manager to use other data to judge whether to Make progress adjustments.

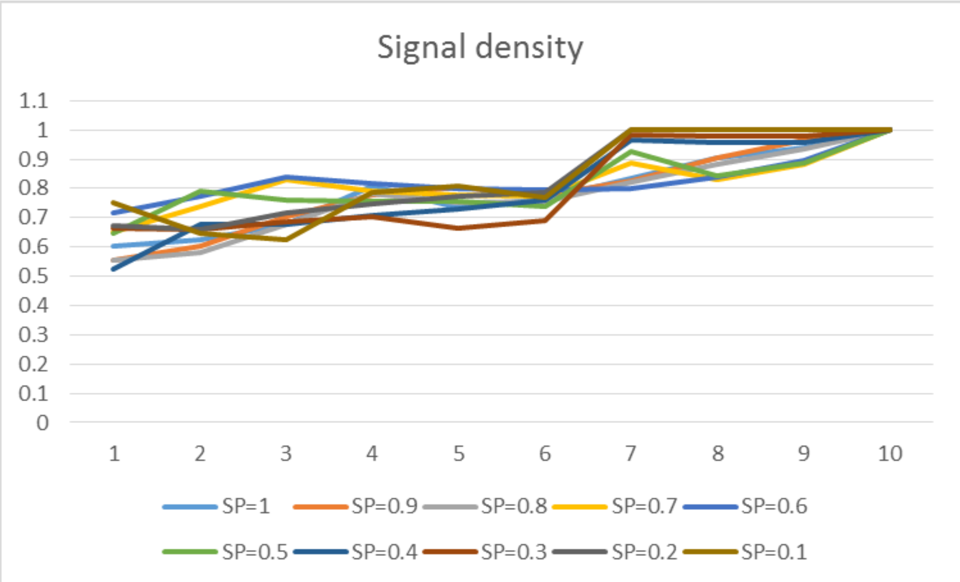


Fig. 3. Signal Density for Different SP Value Items

2) Signal redundancy means that the average amount of warning signals generated during the project life cycle of completing the project in a timely manner will be unfavorable to the project manager during the project management process. From Fig.4, it is observed that the project SP value is high and low, and the number of signal redundancy in the middle to late stage of the project is too large, and the SP value centered project has a large number of signal redundancy in the middle and early stages of the project. When the project manager actually monitors the project, the items with different SP values need to pay attention to the management disadvantage caused by signal redundancy during the above period.

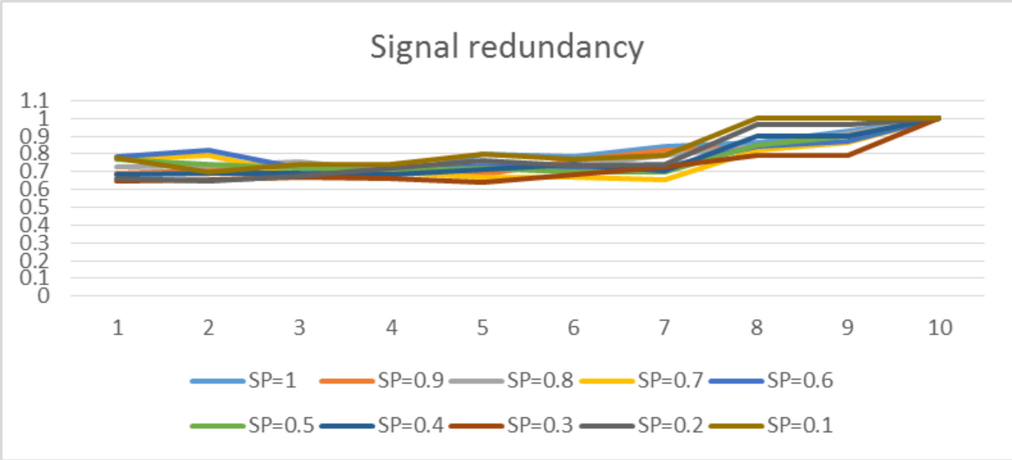


Fig. 4. Signal Redundancy for Different SP Value Items

3) Signal efficiency combines correct and erroneous warning signals and indicates the relative number of correct warning signals generated by the monitoring. The correct alarm signal allows project managers to make timely adjustments to the progress of the project. High signal efficiency has a positive effect on project managers monitoring projects. From Fig. 5, it can be seen that as the uncertainty of the project monitoring progresses, the signal efficiency of the project becomes higher and higher. The project with SP between 0 and 0.5 is in the early stage of the project compared with the SP at 0.6 to 1 The signal efficiency between the projects is high. The project manager can judge the alarm signal generated during project monitoring based on the SP value of the project, requiring the manager to pay special attention during the stage of low signal efficiency.

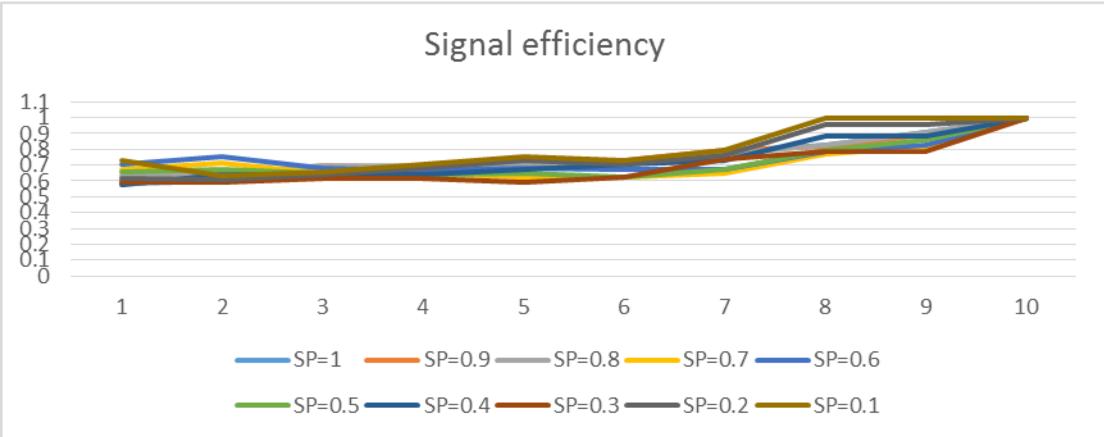


Fig. 5. Signal Efficiency of Different SP Value Items

4) Signal reliability indicates the relative number of error warning signals generated during monitoring. The higher the signal reliability, the greater the probability that the project monitoring and early warning information is wrong. The results in Fig. 6 indicate that as the monitoring progresses, the signal reliability of the project becomes smaller and smaller, that is, the number of false alarms in the project becomes less and less, and at the same time, the signal reliability of the project during the progress of 30% and 70% will be With a slight increase, the alarm signal of the project may be distorted at this stage, and project managers should pay more attention to it.

5) Signal validity is an indicator used to measure the relationship between the number of alarms in a project and the number of delays in the project. In the results shown in Fig. 7, the signal's effectiveness is closer to 1 as the project progresses, and the SP value of the project is between 0 and 0.5. The project's signal validity is between 60% and 80%. The project's signal validity between the project's SP value between 0.6 and 1 is 30%—50%. Project managers need to adjust the control according to the SP value of different projects during project monitoring to prevent false alarm signals from affecting project monitoring.

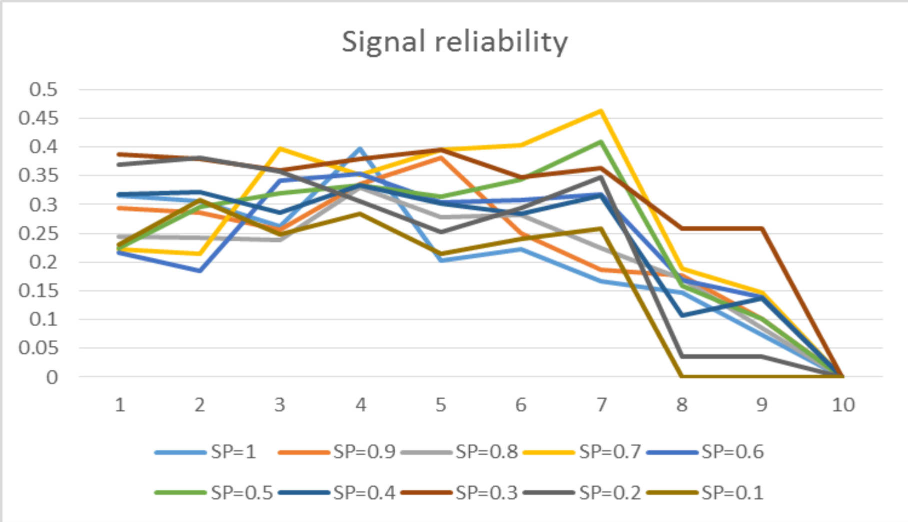


Fig. 6. Signal Reliability for Different SP Value Items

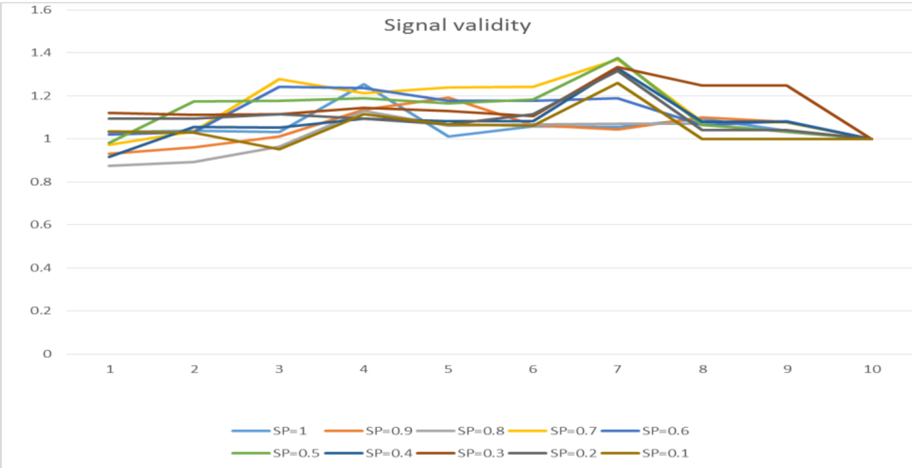


Fig. 7. Signal validity for different SP value items

## 5. The Deficiencies and Prospects of this Article

In this paper, Monte Carlo simulation is used to study the influence of different project network topology on project control. In the course of the experiment, independent assumptions are made on time estimates between projects. However, many processes in the actual project are time-consuming. It is the project linkage. At the same time, this article guarantees that the key route of the project remains unchanged in the experimental process. The actual project is the key line for dynamic adjustment. The researcher can consider this issue in future research. In addition, the linear monitoring method was chosen for the monitoring time of this article, and the researchers can also make innovations in the selection of monitoring time points.


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