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Activity and value orientated decision support for the development planning of a theme park

Ren-Jye Dzeng *, Hsin-Yun Lee

Department of Civil Engineering, National Chiao-Tung University, 1001 Ta-Hsueh Road, Hsinchu 30050, Taiwan, ROC

Abstract

The development of a large theme park usually includes multiple phases. The combination and development ordering of facilities in these phases have a great impact on the attractiveness of the theme park. Examples of such facilities are attractions, food service, accommodation, and supporting facilities. Some of these facilities although highly profitable, cannot attract visitors on their own, while others may boost the visitor count, yet by themselves do not make a profit. This research considers the values that each development activity brings to the project, and prioritizes feasible alternatives based on their net present values. Based on the integration of simulation and the genetic algorithm, a decision support system has been developed to determine the combination and ordering of facilities, and the resources needed for each development step. This development plan will provide investors with systematic and quantitative information that will help them to determine the development portfolio of each facility under the constraint of the funding program.

Keywords: Theme park; Development plan; Genetic algorithms; Simulation

1. Introduction

Developing a theme park may often span decades, requiring a high level of capital investment, and a large parcel of land to build a large number of facilities on. Consequently, the project scheduling is usually contracted out to a consulting firm, and includes: (1) a project feasibility study and an estimate of the development scale; (2) the initial design concept of the facilities; (3) a stage-based development progress and a financial model; and (4) a list of the detailed designs of facilities that need to be developed.

Inappropriate strategy as well as incorrect scheduling may cause the failure of any development project, and especially that of a theme park. Disneyland Resort Paris is a case in point. Within eighteen months after its opening, it had lost 10 billion US dollars. Up to December 1993, less than two years after the opening, not only was the initial capital consumed, but they had to raise an additional loan of 1.75 billion US dollars to maintain the operation (Spencer, 1995). Three months later, a new crisis threatened its survival. Two major oversights attributed to the failure of this development project. First, Paris is located at about 48° latitude, and relatively close to the North Atlantic Ocean, resulting in cold and wet winters. This fact alone will drastically decrease the enthusiasm of people to participation in the outdoor activities offered by the theme park. However, this fact was simply neglected. Second, even though the visitor count was expected to decrease in the cold wintry months, excessive shows and activities kept being launched, resulting in an even further waste of capital. An additional issue that was not considered or investigated was the fact that there is a fair amount of "anti-Americanism" in France, and Disney is seen as the epiphany of US commercialism by many French as well as many Europeans.

The case of Disneyland Resort Paris shows the vital importance of having the right strategy and a correct schedule prior to even executing such large a project. During the extensive period of project development, continuously changing risks become embedded in the construction cost

* Corresponding author. Tel.: +886 3564 7525; fax: +886 3571 6257.
E-mail address: rjdzeng@mail.nctu.edu.tw (R.-J. Dzeng).

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affecting the operation of each facility, as well as the relationship between facilities, especially those involving the supply of resources. The fact that the planner will have to consider multiple variable factors simultaneously is inevitable. This will make it very difficult to settle on an optimal development strategy among the multitude of combinations of potential facilities and scheduling plans. Therefore, support in the decision making process of the development schedule will aid the planner to better understand the influence of each variant on the project outcome, as well as the effectiveness of each schedule combinations, allowing him to determine the optimal development strategy.

Various researches have focused on the issue of modeling the project decision-making and plan optimization, such as the Multi-Criteria Decision Model (e.g., Hsieh & Liu, 1997), Resource-Constrained Scheduling (e.g., Leu & Hwang, 2002), and the Ranking and Combination of the Project Investment Model (e.g., Ghasemzadeh & Archer, 2000). These models are unsuitable for theme park development projects because they cannot simultaneously deal with selection, ordering, and scheduling of feasible investment items.

For example, Hsieh and Liu's Time-series Combinatorial Planning Model in Infrastructure Plan (Hsieh & Liu, 1997) has two assumptions: (1) sub-projects are independent to each other, and (2) activities cannot be separated or partially completed. These two assumptions are unsatisfactory for a theme park development. Example 2, Most Resource-Constrained Scheduling models fail to consider the selection of activities (i.e., not every activity must be executed) but can only provide solutions with specified activities and resources. Example 3, Ghasemzadeh and Archer's supporting system for decision making of a portfolio with multiple items (Ghasemzadeh & Archer, 2000) fails to consider potential situations when the start and finish dates of items are movable.

This study is aimed at constructing a decision support system for the decision-making process when laying out the order of a development plan. The project planner inputs the activities, their start and finish dates, estimated costs and revenues, and resource relationships. All these data are simulated and analyzed in order to predict the overall effectiveness of the project. Various schedule combinations will be calculated to determine the best development strategy so as to provide the planner with a point of reference. This will help overcome the complexities of the decision-making in the development of a theme park facility. This study attempts to achieve its goal through the following approaches:

(1) Investigate the characteristics of a theme park development project, the different types of facilities and their features, characteristics of different types of strategies and scheduling systems, and the demand, supply, and the effect of different facilities.
(2) Construct a simulation network model of a theme park development project, that includes all the features and correlations of the activities involved in the planning, construction, and operation.
(3) Integrate the polyploidy genetic algorithm (GA) and the simulation analysis to design a decision support system for determining the project strategy and schedule plan with the maximum net present value (NPV) for the reference of project investors and planners.

2. Characteristics of a theme park

2.1. Type of project

A theme park development project is a subcategory of land development. While other development projects are intended to be rented, sold or used as an operating facility, a theme park facility is constructed and has a cost efficiency model that are aimed at recreation and entertainment. It has 3 main characteristics:

(1) It requires a large investment of resources: A comparatively large parcel of land is required for a theme park, such as 105 hectares for the Six Flags Magic Mountain, Los Angeles, USA. In addition, very large capital investments are needed for the construction of facilities; for example, "Floorless Coaster" in Janfusun Fancyworld of Taiwan costs $ US 13 million, which is similar to other roller coasters in other theme parks. Also, the need for human labor to operate the facilities once they are built is enormous, such as Disneyland Resort Paris with as many as 12 000 employees (Wylson & Wylson, 1994).
(2) Simultaneous progress of construction and operation: Due to the huge scale of theme parks, the development project is often decomposed into several segments to be executed in different periods or locations, resulting in the construction of one set of facilities while operating another set. The revenue gained from operating the facilities already built becomes an essential source of capital for financing the construction of the other facilities. A properly staged development project can drastically reduce the initial capital requirements, as well as restrain the cash flow within a secure condition.
(3) Multiple variable factors and risks: As a result of the extended length of time and the large number of facilities involved in the development of theme parks, many of the factors that may impact upon the overall performance of the project tend to vary with time, such as the preferences of the customers (old facilities tend to gradually lose favor) and risks from the natural environment (such as, seasonal climatic variations or acts of God like earthquake). Some factors may influence only specific facilities, such as water slide, boating, and other outdoor water activities which are subject to the impact of the weather. Also, construction costs and the costs to operate a facility vary with the fluctuation of the price index.

Table 1
Comparison of different projects

Characteristics	Theme park development projects	Construction projects	Portfolio projects
Project planning tasks	☐ Selection of development items ☐ Scheduling	☐ Scheduling	☐ Selection of investment items ☐ Allocation of capitals
Strategic objective	☐ Maximum project benefits	☐ Shortest duration ☐ Lowest cost	☐ maximum project benefits
Activity continuity	☐ Usually assumed as non-continuous	☐ Usually assumed as continuous	☐ Usually assumed as continuous
Activity relationship	☐ Sequential relationship ☐ Sharing and support of resources among activities	☐ Sequential relationship	☐ No sequential relationship
Resource utilization/production	☐ Utilization ☐ Production	☐ Utilization	☐ Utilization ☐ Production
Resource allocation	☐ Consideration of both utilization and production	☐ Leveling of only resource utilization	☐ Consideration of both utilization and production

A theme park development project differs from a construction or portfolio project, as shown in Table 1. A theme park development project has unique features, such as frequent non-continuity and a close resources sharing/support relationship between activities, making it more complicated than the other two project types.

2.2. Facilities

Previous research into theme park operations revealed that theme park facilities must expand continuously in order to maintain their attraction to the visitors (Wylson & Wylson, 1994). This characteristic demands constant investment of resources in new facilities to maintain and increase revenue. Table 2 shows some of the common facilities in theme parks.

Attractions play a crucial role in drawing ticket-buyers to a theme park. Each attraction has its own product life cycle for its ability to attract visitors, with a profit that fluctuates over time. In general, an attraction that has a higher initial cost may remain attractive for a longer period. In addition, whether or not neighboring resorts provide similar attractions also has a considerable influence on the level of revenue. The gross income of certain attractions is subject to seasonal peaks. For example, in Northern Europe where the weather is often too cool for water activities even during the summer months, most water parks are designed indoors, and provide year-round entertainment. On the other hand in Southern Europe and Southern USA, many water parks are built outdoors and are open for only a few months each year (Wylson & Wylson, 1994). The development and construction of large-scale facilities usually takes a long time, and some may even require 2–3 years from the initial design phase, through the ordering from the vendor, construction, and installation, to operation.

As shown in Table 2, attractions can be categorized into five types; mechanics, scenes, shows, electrical instruments, and sports. With the advances in both electrical and mechanical technologies, the attractions are becoming more versatile. A complete theme park is composed of various types of attractions to satisfy visitors of all ages and preferences.

In addition to attractions, providing food services, commodities, and accommodations are an additional source of considerable profits. For example, in the Six Flags theme parks, 55% of the total revenue comes from theme park

Table 2
Common facilities in theme parks

Type		Common facilities
1. Attractions	Mechanics	Roller coaster, Ferris wheel, Merry-go-round
	Scenes	Garden, maze, ghost house, zoo
	Shows	Outdoor theater, 3D theatre, animal show or acrobatics, fireworks
	Electrical instruments	Electrical game park, space trip simulator, remote control car racing
	Sports	Horseback riding, boating, golf course
2. Food service		Restaurant, snack bar, vendor machine
3. Commodity selling		Souvenir shop, shopping alley
4. Accommodation		Hotel, camping ground, villa
5. Service facilities		Roads, parking lot, ticket box, phone booth, toilets, visitor center, tour bus service
6. Supporting facilities		Administration office, water treatment plant, cremator, common duct

admissions, and 45% comes from food, merchandise, accommodations and others (Six Flags Co., 2005). Accommodation facilities include hotels, villas, and camping grounds, all of which may yield significant profits when there are sufficient attractions to entertain the visitors for more than one day. In Disneyland Resort Paris, Walter Disney Co. built 5 hotels and 1 large camping ground in the first stage of the whole project, to create profits by satisfying the visitors' demand for accommodation (Wylson & Wylson, 1994).

However, the income gained from the food services, commodity sales, and accommodation strictly depends on the amount of visitors and their average length of stay, all of which is greatly influenced by the ability of the attractions to draw in visitors. Therefore, the construction and operation schedule of these facilities must correspond with the development and the scale of the attractions in order to avoid the wasting of resources caused by hasty development.

The other two facilities in Table 2 are service facilities and supporting facilities. Service facilities refer to equipment that can be used by visitors but doesnot provide entertainment, while supporting facilities maintain the operation of the whole theme park. Except for the parking lot, most of the supporting facilities do not yield income, but they are crucial to the sound operation of the attractions, the food services, commodity sales, as well as the accommodations. Usually, service and supporting facilities are necessary for the operation of theme parks, yet many of them can be constructed stage by stage and in accordance with the development of the theme park's scale, such as roads.

The above characteristics indicate that timely development of facilities for the allocation of limited resources is important for generating optimal revenue. A cycle of "develop–operate–create income–invest income in further development" is created in the project scheduling to achieve optimal profits of the whole project.

2.3. Supply, demand, and effect of facilities

The allocation of the type of facilities, the quantity, and the scale must all be based on the potential to draw visitors and the potential profits that can be obtained thereof, as estimated by a detailed market survey (Wylson & Wylson, 1994). Target subjects are usually divided by the distance they live away from the theme park. The majority of the visitors, 70–80% of the total, spend 2–3 h on getting to the theme park. Research methods for determining market scale and for sales forecasting of products and/or services are not discussed in this paper.

The construction and operation of any facility in a theme park development project must be carefully considered in conjunction with external and internal effects. External effects refer to, for example, when the launching of a merry-go-round may have to compete with a similar attraction in a neighboring resort and therefore may bring in profits less than estimated. Internal effects include a situation where for example a shortage of food services may shorten the length of stay, as well as reducing the level of satisfaction originally anticipated by the attractions provided.

3. Simulation networks

The ordering of the stages of development in theme parks can be arrived at through analysis in simulation networks, in which the relationship between activities can be described by, and the project efficiency can be estimated from, the results of the simulation.

Each facility involved in the development of a theme park must undergo a certain amount of planning, construction, operation, closing, dismantling, and divesting. In project scheduling, each stage can be viewed as an individual activity that includes lead time, cost, and revenue. The cost and revenue of an activity may be viewed as the input and output of capital resource. In addition to capital funds, resources may be generated or utilized by other activities. For example, the operation of a horse-riding field may be utilizing the parking spaces that were created for operating parking lots. This study constructed simulation networks to explain the relationships between the generation and utilization of resources in all activities. These simulation networks are based on the CYCLONE (Halpin, 1974) modeling because it has a clear and simple symbolic structure compared to other simulation techniques. STROBOSCOPE (Martinez, 1996) is incorporated in this simulation analysis program with setting options for priority values, making it appropriate for system architecture in this study.

3.1. Activities and resources

The simulation network in Fig. 1 is designed for project activities involving a roller coaster. The duration of each *Combi* (Units arriving at *Combi* will be processed if units are available in each preceding *Queue* node.) in this figure occurs in the same time unit, which can be set as one month, one quarter, or one year. Both *Combi* and *Queue* (*Queue* provides a position that allows units to be delayed pending *Combi* activities) can be divided into two categories, actual and virtual.

3.1.1. Actual activity and resource

Combi and *Queue* denote the actual activity and resource in project scheduling. In Fig. 1, there are seven actual activities, *Design_RollerCoaster*, *Construct_RollerCoaster*, *Operate_RollerCoaster*, *Operate_Hotel*, *Operate_SouvenirShop*, *Operate_ParkingLot*, and *Operate_SupportFacilities*, as well as five actual resources: *Cash*, *Parking_Capacity*, *Support_Capacity*, *SouvenirShop_Demand*, and *Lodging_Demand*. They have a utilization relationship with each other. For example, *Parking_Capacity,* which is as a result from the execution of *Operate_ParkingLot*, is consumed by visitors who are drawn by *Operate_RollerCoaster*. On the other hand, *SouvenirShop_Demand* and *Lodging_De-*

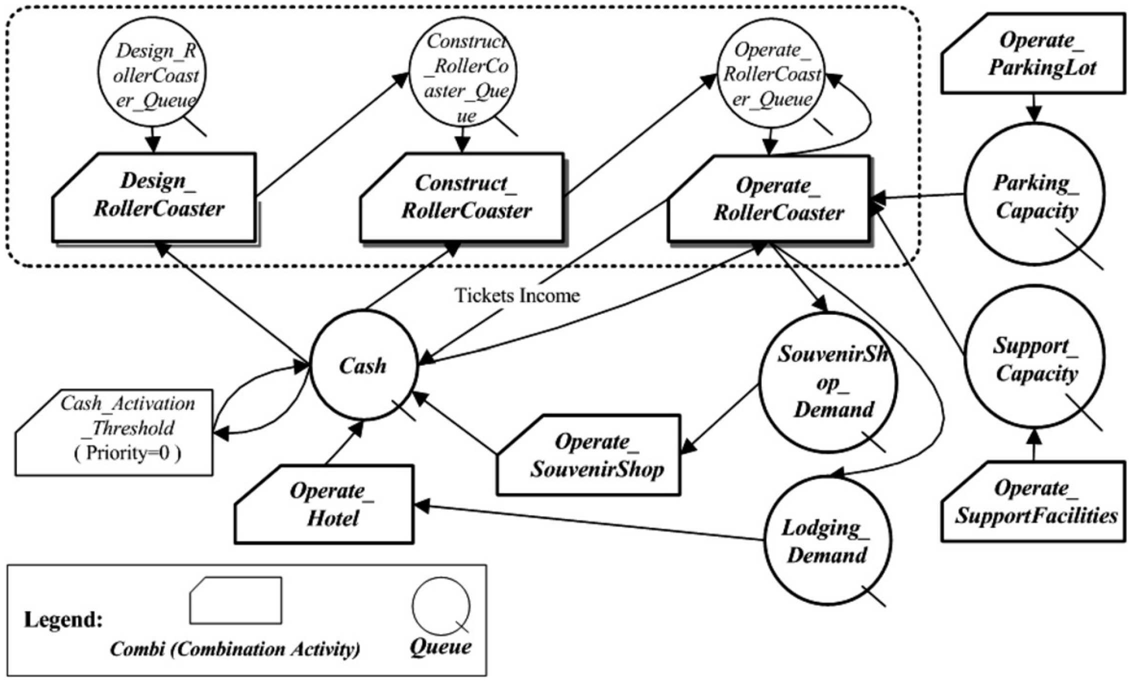

Fig. 1. Simulation network of roller coaster.

mand are as a result from *Operate_RollerCoaster*, and these demands may influence the revenues (which later become *Cash*) generated by *Operate_SouvenirShop* and *Operate_Hotel*.

Actual resources can be divided into accumulative and non-accumulative ones. Since the duration of each *Combi* is fixed as one time unit, the surplus of some resources may be accumulated to be used in the following time unit (such as *Cash*). However, some resources cannot be accumulated, such as *Parking_Capacity*.

An actual activity, expressed as a *Combi*, is executed (or not) according to the sufficiency of the resources required. In reality, the execution of a project shows different degrees of priority in the utilization of the same single resource among different activities. For example, parking lots with limited capacity should be used for facilities that can generate a higher return. In STROBOSCOPE, each activity possesses a priority value, either fixed or variable. At a certain point in time, an activity with a higher priority value implies a higher execution moment. The execution value of an activity depends on current or future "direct revenues derived as such" and "their contribution to facilitate the operation of other facilities". For instance, a roller coaster has an execution value because it provides direct income from ticket sales; while service facilities, such as roads, also have their own execution value even though they may not yield direct revenue they facilitate the smooth operation of the roller coaster that brings income. In other words, the revenue of the roller coaster shows the execution value of both the roller coaster and the service facilities.

In our research, the priority value of each activity to resource utilization is applied to determine the execution value. Set between 0 and 1, the relative measures of the priority values are used to control the dynamic balance between the supply and the demand of the resources. For example, when both *Construct_RollerCoaster* and *Design_FerrisWheel* needed *Cash* at the same time, the activity with the higher priority value should be given preference.

3.1.2. Virtual activity and resource

Virtual activity does not exist in actual project scheduling; rather, its purpose is to determine whether the activity or project should be carried out or not. Postponing the execution of activities when enough resources are available should be controlled by virtual activity. Even when provided with sufficient resources, sometimes activities in a theme park development project may be postponed for a few reasons. One example is the case of *Operate_ParkingLot*, which is expected to be sufficient, and is supposed to have been supported by the income it produced during the year. There is no capital money to be invested in the expansion of the parking lot, because an overcapacity in parking would cause unnecessary cost for maintenance and management. Each virtual activity has a corresponding actual resource (such as *Cash_Activation_Threshold*, in Fig. 1, corresponding to the actual resource *Cash*). A comparison of priority values between virtual activity and actual activity that intend to use the resource in question is conducted to determine the priorities of resource utilization and allocation. The priority value of each virtual activity is 0 while those of the actual activities that could be executed fell between 0 and 1. On the other hand, the virtual activities hinder the execution of the actual activities with a priority value of −1 by capturing all the corresponding resources, even when sufficient resources are available.

The virtual resources are used to control the activity sequence. Activities associated with one facility may feature a sequential order. In the case of the roller coaster, activities should abide by the order of "design–construct–operate", in which the execution of the next step shall not be prior to the completion of the previous one.

Fig. 1 shows that the three virtual resources (*Design_RollerCoaster_Queue*, *Construct_RollerCoaster_Queue*, and *Operate_RollerCoaster_Queue*) correspond to the three actual activities. For example, the virtual resource *Design_RollerCoaster_Queue* corresponds to the actual activity *Design_RollerCoaster*. In the beginning, the quantity of the stand-by resources is set as 1, and the execution of *Design_RollerCoaster* for a unit of time may consume 1/6th of *Design_RollerCoaster_Queue*. After 6 units of time, all the *Design_RollerCoaster_Queues* are consumed, indicating that *Design_RollerCoaster* is completed with a quantity of *Construct_RollerCoaster_Queue* as 1, which further triggers the execution of the activity *Construct_RollerCoaster*.

3.2. Execution value of activities

In the above simulation network, the priority value of the activity decides whether the activity may be executed, indicating the execution value of that activity at that point in time. Combining all the priority values of the activities for all units of time is the project development strategy, and the start and finish date of each activity estimated in the simulation with priority value combinations will be the project schedule.

Since various factors must be considered in the evaluation of the execution value of an activity, project planners may find it difficult to determine the optimal plan with only individual judgments and experiences. Therefore, this study is facilitated by a computer in order to construct an application system. The GA was applied in the search of a near-optimal solution from combinations of priority values of activities. In addition, viewpoints of activity execution value are included to achieve optimal project scheduling.

4. Architecture of AVO-PLAN

This study attempts to construct an AVO-PLAN (Activity-Value- Oriented PLANning) decision support system, in order to facilitate the decision-making process of development ordering of facilities in theme parks. Since the problem-solving of this issue has features of multiple periods and situations, employing a polyploidy GA structure is an ideal approach to combine development strategies of each period into a plurality of chromosomes. At the same time, a large number of development strategy combinations can rapidly reach convergence and solution. An estimate on the project NPV of each development strategy can be obtained from the simulation.

4.1. Application of a polyploidy GA

Since the introduction by John Holland in 1975 (Holland, 1975), the GA has been gradually applied to a wide range of fields. However, the traditional GA usually applies the genetic structure of haploid, in which single-dimensional genetic encoding is severely limited to express potential solutions. In the real world, many problems feature multi-periods, multi-steps, or multi-situations. Therefore, a polyploidy genetic structure may express and reveal more practical solutions.

The genetic structure of polyploidy can be seen in a gene composed of multiple chromosomes. Human genes, for example, are diploid type with 23 sets. In fact, the polyploidy structure is very common among creature in nature, including diploid, triploid, and teraploid. Fig. 2 shows a diagram for haploid, triploid, and complex chromosomes (Wu, 2002). Haploid genes are usually utilized to express a biological appearance (such as skin color), while a polyploidy structure may be viewed as a combination of several haploid genes.

Polyploidy structure provides various phenotypes or applicable behaviors, so that individuals may perform different strategies for survival during changes in the environment. On the other hand, the polyploidy structure still follows the model of genetic dominance proposed by Mendel in the 19th century, in which only one chromosome among all others in the polyploidy gene would become the phenotype for the organism at a single period of time (Wu & Sun, 2002).

The polyploidy may be applied to solve complex issues with multiple situations or parameters. Collingwood observed the process of searching for the optimal solution for the analytical comparison between the effects of a polyploidy and a haploid GA. It was found that, since the polyploidy structure conserves more information, more opportunities to achieve better solutions may be obtained from it rather than from the haploid structure for the same issue (Collingwood, Corne, & Ross, 1996).

Many studies have been proposed applying the polyploidy GA to construct problem-solving models. For example, Wu and Sun constructed the fuzzy dominances of several typical fuzzy models in a study that applied

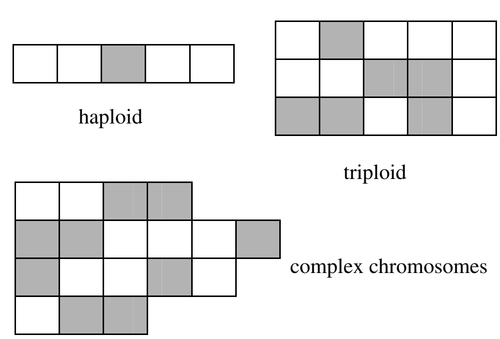

Fig. 2. Haploid, triploid, and complex chromosomes.

polyploidy structure to the structure of membership functions (Wu, 2002) (Wu & Sun, 2002). Their experimental results revealed that the proposed model could not only effectively solve problems of multiple situations but also evolved into adequate polyploidy structure, featuring advantages in performance and efficiency (Wu, 2002).

The multi-period and multi-situational issue in this study may be solved under the structure of polyploidy genes, in order to record and modify the strategies of the project activities in each time unit.

4.2. Integration of simulation and GA

The integration of simulation and GA has been applied to many different fields, because it may yield a satisfactory result in the search for an optimal solution. In construction projects, for example, Cheng and Feng integrated CYCLONE and the GA to develop a GACOST system. Their study presented a mechanism that integrates simulation with the GA to find the best resource combination for a construction operation (Cheng & Feng, 2003). In addition, Marzouk and Moselhi integrated simulation and the GA to estimate the time and cost of earthmoving operations (Marzouk & Moselhi, 2002).

A similarity between theme park development projects and other studies that applied simulation lies in the huge number of uncertainties and the probability distribution of the data (such as the ticket income). On the other hand, the difference is that the development ordering is based on the execution value of the operations. Instead of incorporating the start and the finish date of each activity into the genetic coding, this approach calculates the priority value of each activity in each time unit. In addition, the priority value of each time unit is regarded as an independent chromosome, and all the chromosomes are combined together to form a polyploidy. Thus, the structure can be

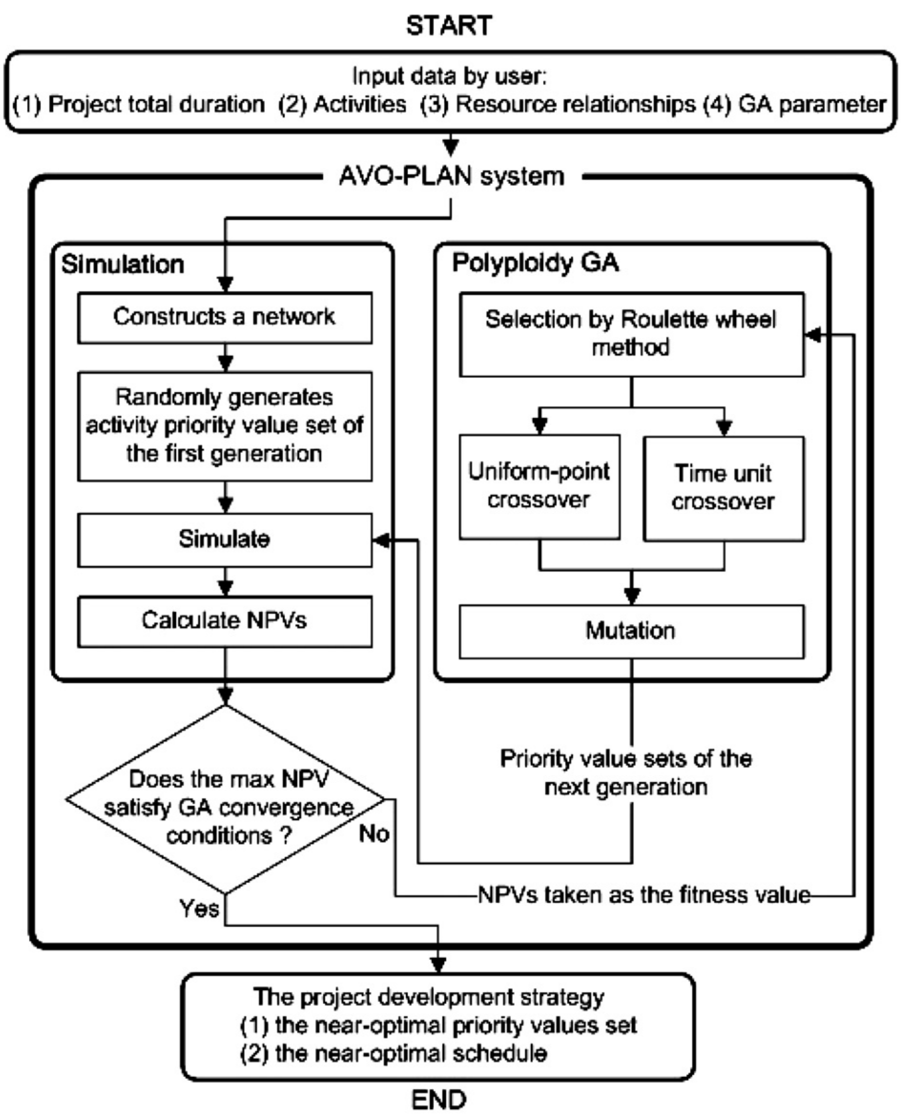

Fig. 3. The process of AVO-PLAN.

better expressed than in other studies with only one chromosome (haploid).

4.3. Constructing the system

As shown in Fig. 3, AVO-PLAN is comprised of two sub mechanisms: simulation and the polyploidy GA. After inputting data by the user, AVO-PLAN automatically constructs a simulation network and then conducts the polyploidy GA with NPVs calculated from the results of the simulation. Conditions for convergence toward near-maximum NPV are then determined after constant selections via generations, in order to end up with the near-optimal priority value strategy combination and project schedule.

First, the user is required to input the total duration of the project for calculating the NPV. Also, the user has to input activity information of each facility to be developed (including name, duration, and resources) and the demand-and-supply relationship of the resources between each activity. In addition, the parameters of the polyploidy GA are indispensable, including the initial number for population size, generation size, crossover rate, and mutation rate.

Second, AVO-PLAN constructs a simulation network in accordance with the data input by the user. Each activity in this network has a priority value, to which the resource application sequence is referred. All the priority values of each activity are incorporated into a set of priority values, which then undergoes simulation analysis. Estimations on cash flow of the project are then obtained from the simulation results, followed by the calculation of the NPV.

Third, the NPV derived through the calculation in the simulation analysis is taken as the fitness value for the GA. The near-optimal solution is then determined by the judgment of whether this fitness value satisfies the conditions for convergence in the GA. In order to incorporate the priority values set into the polyploidy GA, AVO-PLAN randomly generates a priority value set of the first generation as the genetic code.

In each time unit T, each activity possesses a priority value. As $T = i$, activity A_1 has a priority value of $P_{1,i}$, and the priority value set of n activities $(A_1, A_2, \ldots, A_n)$ at $T = i$ can be stated as $P_{1,i}, P_{2,i}, P_{3,i}, \ldots, P_{n,i}$., the genetic encoding of a chromosome is therefore constructed. If a project spans a period of m time units (such as 120 months, 40 quarters, or 10 years) in total, then the genetic encoding of the priority value sets at each time unit combines into a

Table 3
Genetic code of priority value sets as $T = 0 \sim m$

	A_1	A_2	A_3	A_4	A_5	...	A_n
$T=0$	$P_{1,0}$	$P_{2,0}$	$P_{3,0}$	$P_{4,0}$	$P_{5,0}$	...	$P_{n,0}$
$T=1$	$P_{1,1}$	$P_{2,1}$	$P_{3,1}$	$P_{4,1}$	$P_{5,1}$	...	$P_{n,1}$
$T=2$	$P_{1,2}$	$P_{2,2}$	$P_{3,2}$	$P_{4,2}$	$P_{5,2}$	...	$P_{n,2}$
$T=3$	$P_{1,3}$	$P_{2,3}$	$P_{3,3}$	$P_{4,3}$	$P_{5,3}$	...	$P_{n,3}$
$T=4$	$P_{1,4}$	$P_{2,4}$	$P_{3,4}$	$P_{4,4}$	$P_{5,4}$	...	$P_{n,4}$
$T=5$	$P_{1,5}$	$P_{2,5}$	$P_{3,5}$	$P_{4,5}$	$P_{5,5}$	...	$P_{n,5}$
...	...	...	...	...	...	...	...
$T=m$	$P_{1,m}$	$P_{2,m}$	$P_{3,m}$	$P_{4,m}$	$P_{5,m}$	...	$P_{n,m}$

	A_1	A_2	A_3	A_4	A_5	…	A_n
T=0	0.21	-1	0.15	0.85	0.05	…	0.33
T=1	0.77	0.34	0.73	-1	0.41	…	0.81
T=2	-1	0.61	0.34	0.98	0.18	…	-1
T=3	0.03	0.88	0.27	0.46	0.62	…	0.59
T=4	0.16	0.25	0.92	0.78	0.55	…	0.11
T=5	0.82	0.02	0.68	-1	0.29	…	0.09
…	…	…	…	…	…	…	…
T=m	0.52	-1	0.09	0.57	0.38	…	0.07

	A_1	A_2	A_3	A_4	A_5	…	A_n
T=0	0.15	0.42	0.72	0.57	0.55	…	0.37
T=1	0.53	0.78	0.35	0.90	0.11	…	0.66
T=2	0.81	0.91	0.24	0.54	0.24	…	-1
T=3	0.68	0.10	0.81	0.85	0.48	…	0.04
T=4	0.31	0.69	-1	0.72	0.71	…	0.47
T=5	0.02	0.45	0.95	0.36	0.75	…	0.19
…	…	…	…	…	…	…	…
T=m	0.28	0.73	0.08	-1	0.66	…	0.83

uniform-point crossover

	A_1	A_2	A_3	A_4	A_5	…	A_n
T=0	0.21	0.42	0.15	0.85	0.55	…	0.33
T=1	0.53	0.34	0.73	-1	0.11	…	0.66
T=2	-1	0.91	0.24	0.98	0.18	…	-1
T=3	0.03	0.88	0.27	0.85	0.62	…	0.59
T=4	0.31	0.25	-1	0.78	0.71	…	0.11
T=5	0.82	0.02	0.95	0.36	0.29	…	0.19
…	…	…	…	…	…	…	…
T=m	0.28	0.73	0.08	0.57	0.38	…	0.83

	A_1	A_2	A_3	A_4	A_5	…	A_n
T=0	0.15	-1	0.72	0.57	0.05	…	0.37
T=1	0.77	0.78	0.35	0.90	0.41	…	0.81
T=2	0.81	0.61	0.34	0.54	0.24	…	-1
T=3	0.68	0.10	0.81	0.46	0.48	…	0.04
T=4	0.16	0.69	0.92	0.72	0.55	…	0.47
T=5	0.02	0.45	0.68	-1	0.75	…	0.09
…	…	…	…	…	…	…	…
T=m	0.52	-1	0.09	-1	0.66	…	0.07

Fig. 4. Uniform-point crossover of polyploidy genes.

	A_1	A_2	A_3	A_4	A_5	...	A_n
T=0	0.21	-1	0.15	0.85	0.05	…	0.33
T=1	0.77	0.34	0.73	-1	0.41	…	0.81
T=2	-1	0.61	0.34	0.98	0.18	…	-1
T=3	0.03	0.88	0.27	0.46	0.62	…	0.59
T=4	0.16	0.25	0.92	0.78	0.55	…	0.11
T=5	0.82	0.02	0.68	-1	0.29	…	0.09
…	…	…	…	…	…	…	…
T=m	0.52	-1	0.09	0.57	0.38	…	0.07

	A_1	A_2	A_3	A_4	A_5	...	A_n
T=0	0.15	0.42	0.72	0.57	0.55	…	0.37
T=1	0.53	0.78	0.35	0.90	0.11	…	0.66
T=2	0.81	0.91	0.24	0.54	0.24	…	-1
T=3	0.68	0.10	0.81	0.85	0.48	…	0.04
T=4	0.31	0.69	-1	0.72	0.71	…	0.47
T=5	0.02	0.45	0.95	0.36	0.75	…	0.19
…	…	…	…	…	…	…	…
T=m	0.28	0.73	0.08	-1	0.66	…	0.83

time unit crossover

	A_1	A_2	A_3	A_4	A_5	...	A_n
T=0	0.21	-1	0.15	0.85	0.05	…	0.33
T=1	0.53	0.78	0.35	0.90	0.11	…	0.66
T=2	-1	0.61	0.34	0.98	0.18	…	-1
T=3	0.68	0.10	0.81	0.85	0.48	…	0.04
T=4	0.31	0.69	-1	0.72	0.71	…	0.47
T=5	0.82	0.02	0.68	-1	0.29	…	0.09
…	…	…	…	…	…	…	…
T=m	0.28	0.73	0.08	-1	0.66	…	0.83

	A_1	A_2	A_3	A_4	A_5	...	A_n
T=0	0.15	0.42	0.72	0.57	0.55	…	0.37
T=1	0.77	0.34	0.73	-1	0.41	…	0.81
T=2	0.81	0.91	0.24	0.54	0.24	…	-1
T=3	0.03	0.88	0.27	0.46	0.62	…	0.59
T=4	0.16	0.25	0.92	0.78	0.55	…	0.11
T=5	0.02	0.45	0.95	0.36	0.75	…	0.19
…	…	…	…	…	…	…	…
T=m	0.52	-1	0.09	0.57	0.38	…	0.07

Fig. 5. Time unit crossover of polyploidy genes.

polyploidy with multiple chromosomes, which can be used to describe the priority value of the resource utilization of each activity at each time unit, as shown in Table 3.

Fourth, the "Roulette wheel" method was applied to select the priority value set with an equal number to the population size. The probability of selection is proportional to the area in the circle graph; a greater area brings more chances to be selected, which is correlated to the fitness of the individual (Falkenauer, 1999). To avoid excellent individuals from being dropped during the selection process, AVO-PLAN preserves individuals with NPV ranked among the top 5 percentile.

Fifth, the priority value sets selected can undergo crossover and mutation, so as to produce priority value sets of the next generation. In most case, crossover in haploid may be performed in one-point crossover, two-point crossover or uniform-point crossover. Fig. 4 plots the process of uniform-point crossover performed in every gene of the individual, in which the exchange between each gene is independent from each other.

In addition to the crossovers in the haploid GA, the time unit crossover can be executed in the polyploidy GA in this paper, as shown in Fig. 5. The time unit crossover is a kind of crossover performed by all chromosomes at the same time unit. The priority values of the same time unit became a chromosome of polyploidy, and their comparative size determines the demand-and-supply of resources in this particular time unit. After several generations, some of the priority value sets in a certain time unit of the generation individual may have been excellent. A time unit crossover can maintain these superior chromosomes and prevent the chromosome from being broken during crossover. Therefore, timely adoption of a time unit crossover in the selection through generations may very possibly figure out more ideal priority value sets. Further investigation on this hypothesis is discussed in the case study of this paper.

Sixth, the next-generation priority value sets generated via crossover and mutation then undergo another simulation analysis, and the NPV is then decided based on the simulation results. This procedure to generate next-generation priority value sets is continuously repeated till the maximum NPV reaches stability, i.e., satisfies the convergence conditions of the GA. The priority value with maximum NPV becomes the guideline of the project development strategy, by which AVO-PLAN conducts a simulation analysis and uses the results to estimate the near-optimal project schedule, as a reference for the user in project planning.

5. Case study

To understand the advantages brought by AVO-PLAN proposed to the scheduling of a theme park development project, we will compare our system with experts and other methodologies. A case adopted and simplified from "BADA Forest Theme Park in Taiwan" is applied for the analysis and the verification of our system.

5.1. Case introduction

Usually, dozens of facilities are involved in a theme park development project. To facilitate analysis, it is supposed in this case study that only five main facilities are included: (1) attractions (comprising all attractions); (2) parking lot; (3) souvenir shop; (4) hotel and (5) supporting facilities (including water treatment plant, garbage dump, a main sanitary sewer line, and so on). Each facility involves three activities: (1) planning and designing, (2) construction and (3) operation. So, the development project compasses 15 activities in total. Duration is calculated in units of a month (as shown in Table 4), and the operation activity of each facility is performed till the end of the project.

From the beginning of the construction of the infrastructure to the staged expansion after operation has commenced, a theme park development project may span a few decades. With the reduced quantity of facilities and activities in the case study, the total duration of the project is set as 120 months (10 years), so as to facilitate calculation of the NPV. Other factors are considered that may influence the NPV; the annual compounded interest rate is set as 5%, and the linear depreciation to 0 of each facility is set at 20 years.

The Activities and Resources in the case are shown in Table 5. Given that five resources are involved in this case:

1. *Capital*: Available capital in the beginning of the project is NT$ 710 000 000 and no capital increase occurs during the project. Any capitals involved during the operation of the facilities are denoted in units of NT$ /month.
2. *Capacity of parking lot*: This is provided by "operation of parking lot" to satisfy the demands of both visitors and employees during the operation of other facilities. The calculation is based on the time unit of "month" and the capacity is denoted by the unit of "cars/ month", which is 0 at the beginning of the project.
3. *Capacity of supporting facilities*: The calculation unit is "visitor count/ month", which is 0 at the beginning of the project and is provided by the "operation of supporting facilities" to meet the demands from "operation of attractions", "operation of souvenir shop", and "operation of hotel".
4. *Demand for consumption in souvenir shop*: The calculation unit is "NT$/ month" and the value is 0 in the beginning of the project. It is produced by "operation of attractions" and "operation of accommodation" (visitors and hotel customers purchasing souvenirs). The total demand is equal to the capital output from "operation of souvenir shop".
5. *Demand for accommodation*: The calculation unit is "visitor count/ month" and the value is 0 at the beginning of the project. It is produced by "operation of attractions". The total demand x NT$ 650/visitor count equals the capital output from "operation of hotel".

Table 4
Facilities in the case

Facility	Activity	Duration (Month)
F1 Attractions	A1 planning and design of attractions	6
	A2 construction of attractions	16
	A3 operation of attractions	–
F2 Parking lot	A4 planning and design of parking lot	1
	A5 construction of parking lot	3
	A6 operation of parking lot	–
F3 Souvenir shop	A7 planning and design of souvenir shop	2
	A8 construction of souvenir shop	5
	A9 operation of souvenir shop	–
F4 Hotel	A10 planning and design of hotel	6
	A11 construction of hotel	18
	A12 operation of hotel	–
F5 Supporting facilities	A13 planning and design of supporting facilities	2
	A14 construction of supporting facilities	4
	A15 operation of supporting facilities	–

Various types of resources are required in the development of a theme park, but in our case study all the resources except the fifth are omitted. For example, the land required in the project is supposed to have been sufficiently acquired.

5.2. Performance and comparison

Based on AVO-PLAN proposed in this research, an application system was constructed with Visual Basic 6.0, and Stroboscope 2.0.1.7 was applied in the compiling of the project scheduling planning and simulation. Inputting relevant data of the case study into the system constructs the simulation network automatically. Through the natural selection of generations in GA, AVO-PLAN figured out near-optimal solutions of the NPV.

In the case study, the number of solutions with 15 activities is $(15!)^{120}$, which are not likely to be solved individually with the method of exhaustion. Therefore the GA should be applied to enhance the speed in the search of near-optimal solutions. Generally, direct scheduling by GA combines the start and the finish date of each activity as the first generation. An example is "Time-series Combinatorial Planning Model in Infrastructure Plan" proposed by Hsieh and Liu (1997). However, AVO-PLAN in this study applies the priority value of each activity in each time unit for genetic coding. The convergence curves of AVO-PLAN and the direct scheduling by GA are shown in Fig. 6., where the former obviously surpasses the latter. AVO-PLAN is oriented to abide by the activity execution value, making it easier to derive the scheduling for optimization of resource utilization.

Generally the haploid genes structure applies a uniform crossover in which each gene encounters exchange with independent probability. The polyploidy GA constructed in this study may also perform crossovers in terms of time units. In other words, the whole chromosomes of each time unit may be paired for crossover. The application of the

Table 5
The activities and resources in the case

Activity	Resource input	Resource output
A1	R1 Capital: NT$ 30 000 000	–
A2	R1 Capital: NT$ 350 000 000	–
A3	R1 Capital: NT$ 1 050 000/month R2 Capacity of parking lot: 300 cars R3 Capacity of supporting facilities: 15 600 visitor count/month	R1 Capital: NT$ 3 250 000/month R4 Demand of consumption in souvenir shop: NT$ 152 000/month R5 Demand for accommodation: 3600 visitor counts/month
A4	R1 Capital: NT$ 600 000	–
A5	R1 Capital: NT$ 6 800 000	–
A6	R1 Capital: NT$ 200 000/month	R1 Capital: NT$ 525 000/month R2 Capacity of parking lot: 600 cars
A7	R1 Capital: NT$ 350 000	–
A8	R1 Capital: NT$ 6 800 000	–
A9	R1 Capital: NT$ 120 000/month R2 Capacity of parking lot: 60 cars R3 Capacity of supporting facilities: 3 120 visitor count/month R4 Demand of consumption in souvenir shop: A3 (operation of attractions), Total R4 (Demand of consumption in souvenir shop) produced from A12 (operation of hotel)	R1 Capital: A3 (operation of attractions), Total R4 (Demand of consumption in souvenir shop) produced from A12 (operation of hotel)
A10	R1 Capital: NT$ 3 200 000	–
A11	R1 Capital: NT$ 270 000 000	–
A12	R1 Capital: NT$ 1 500 000/month R2 Capacity of parking lot: 100 cars R3 Capacity of supporting facilities: 5200 visitor count/month R5 Demand for accommodation: R5 (Demand for accommodation) produced from A3 (operation of attractions)	R1 Capital: R5 (Demand for accommodation) × NT$650/visitor counts produced from A3 (operation of attractions) R4 Demand of consumption in souvenir shop: R5 (Demand for accommodation) × NT$15/visitor counts produced from A3 (operation of attractions)
A13	R1 Capital: NT$ 1 650 000	–
A14	R1 Capital: NT$ 17 000 000	–
A15	R1 Capital: NT$ 650 000/month R2 Capacity of parking lot: 50 cars	R3 Capacity of supporting facilities: 25 000 visitor counts/month

polyploidy GA in this system is the ''time unit crossover''. The following approaches were adopted in the attempt to understand the effectiveness of ''time unit crossover'': (1) Change even generations after the first generation into ''time unit crossover''; (2) Change even generations after the fifth generation into ''time unit crossover''; (3) Change each generation into ''time unit crossover''. Fig. 7 is the comparison between the convergence curves of the above three modified crossover methods and that with the ''uniform-point crossover in each generation''. With ''uniform-point crossover in each generation'', convergence is completed in the 85th generation at an optimal value of 5415. The most effective modified crossover method is with ''time unit crossover for the even generations after the 15th generation''. It accelerates the convergence in the 69th generation and increases the optimal value to 5718. It can be found that ''time unit crossover'' in appropriate generations may yield better efficiency in the search of better near-optimal solutions than setting each generation as ''uniform-point crossover'' or as ''time unit crossover''.

To understand the difference in effectiveness between AVO-PLAN and a human-being, we invited five experts to complete the scheduling for the case. These experts included 2 managers in real estate development companies, 2 project management consultants, 1 manager of a theme park. They were all familiar with bar charts, the concept of project investment and NPV, and they had practical experiences of over 3 years. Table 6 lists the result of the comparison. Scheduling with AVO-PLAN took 1.3 h (including the user's operation time), which is far less than the average time spent by experts of 5.7 h. Also, the optimal NPV obtained by AVO-PLAN is also higher.

Experts also share a similar opinion that in the past the demand-and-supply relationship of resources between activities were only roughly calculated or even neglected

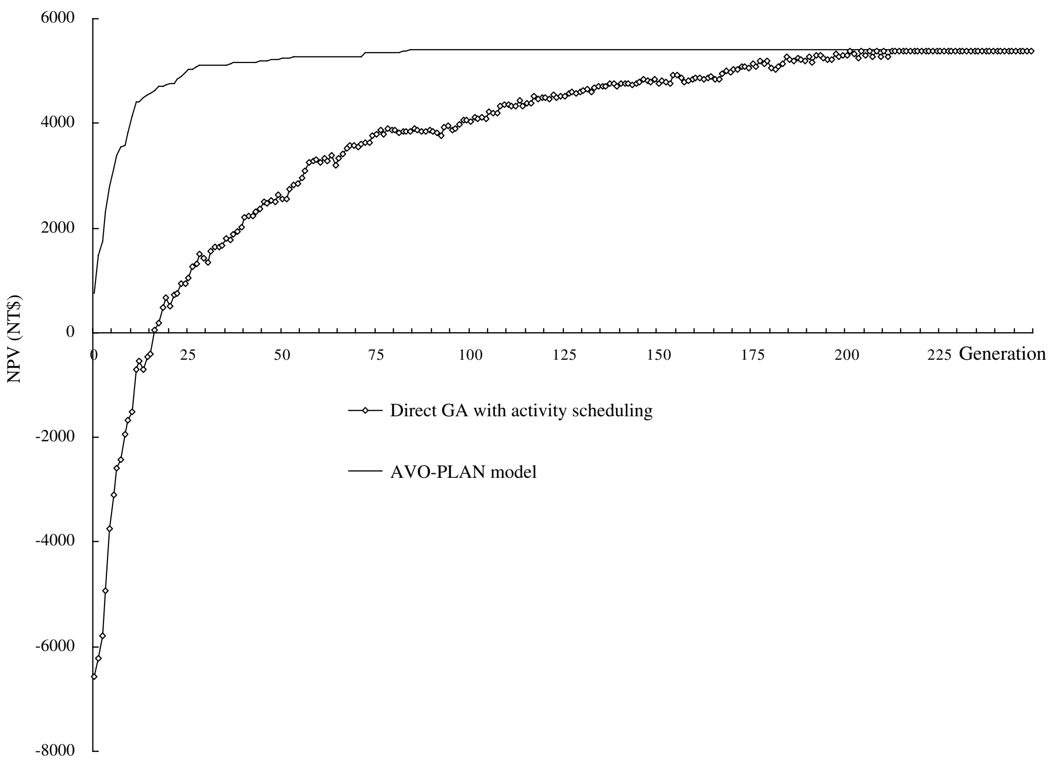

Fig. 6. Convergence curves with AVO-PLAN and direct scheduling by the GA.

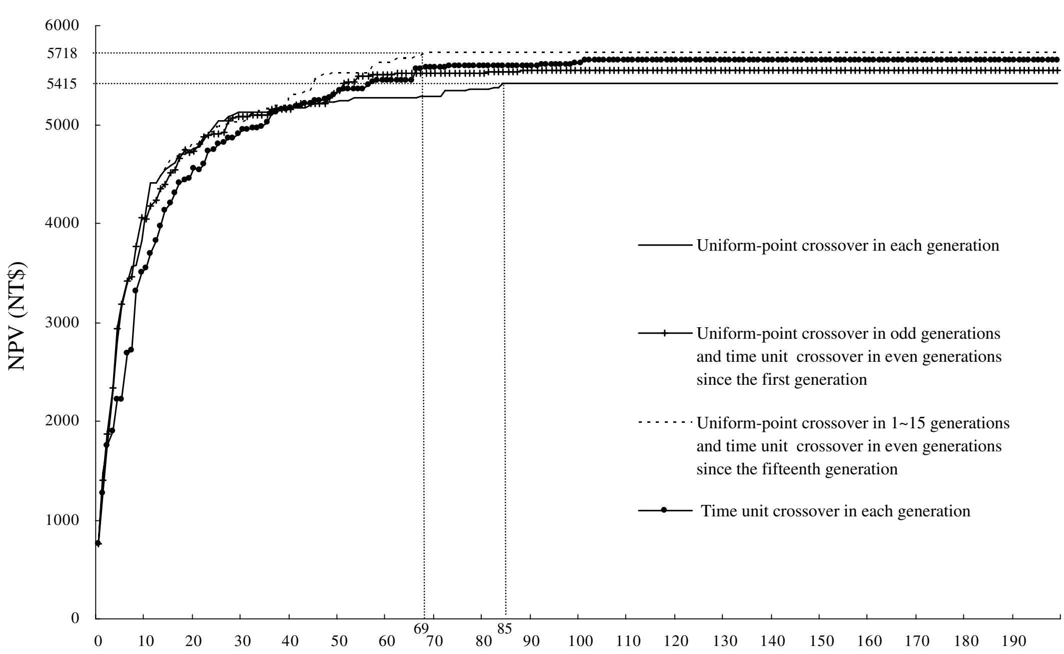

Fig. 7. Influence of "Time unit crossover" on convergence curve.

in scheduling. Including this aspect into the calculation in the case study may better reflect the actual situation, but it also dramatically increases the level of complexity for the scheduling. Repeated calculations have to be carried out to evaluate the influence of different start and finish dates of activities on the cash flow, as well as to confirm whether other activities will be interfered with or must be postponed. After the demonstration in AVO-PLAN, experts also reached the consensus that the integration of the simulation analysis and the GA can indeed enhance project scheduling as well as the efficiency of the search for the near-optimal NPV.

Table 6
Comparison of effectiveness between AVO-PLAN and experts

Result	AVO-PLAN	Scheduling by experts
Time (h)	1.3	Average: 5.7
Optimal NPV (NT$)	5718.4	Average: 4588.7 Max.: 5445.6 Min.: 4084.4

6. Conclusions

Much research has been devoted to project scheduling of construction projects and optimization of financial portfolio. However, very few studies have been dedicated to the problem of theme park development, which requires consideration of both scheduling and portfolio optimization. This study analyzed the features of theme park development projects and divided the associated facilities into five categories.

To facilitate the scheduler to develop the optimal project schedule, the proposed AVO-PLAN system integrates simulation and the GA to predict the NPV of each combination and determine the priorities of each facility with the GA. The priority values of each facility in each time unit are expressed with genetic coding, and the optimal development strategy and scheduling are determined after generations of evolutions.

Since the focus of a theme park development project is the value of the investment items, and since there is a complicated demand-and-supply relationship between activities, the genetic coding with start and finish date of each activity may not reflect the importance of execution for each item. Unlike other studies of scheduling with the aid of the GA, AVO-PLAN incorporates the priority values of each development item in each time unit into genetic coding, so as to facilitate a quicker search of near-optimal solution via simulation. In addition, this study also combined the priority values of each time unit into a polyploidy genetic structure, which provides a better reflection of the Time-series than ordinary applications with haploid.

The testing in our case study revealed that AVO-PLAN surpassed the experts by a faster search and a better NPV. With regards to the demand-and-supply relationship of the resources between activities; the experts couldnot provide a thorough consideration in their scheduling, while AVO-PLAN integrates it completely into the project scheduling via simulation. Scheduling of theme park requires a considerable versatility of combination. In the past, its completion relied on the experience of experts. On the other hand, AVO-PLAN applies the GA to effectively figure out the near-optimal project scheduling for schedulers. Our proposed system can not only be applied to theme park development projects but also to the decision-making and scheduling portions of other projects that require staged or segmented execution, such as staged urban renewal projects.

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