TITLE OF THE INVENTION

PIPELINE REPLACEMENT PLANNING SUPPORT SYSTEM AND PIPELINE REPLACEMENT PLANNING SUPPORT METHOD

BACKGROUND

Technical Field

[0001]

The present invention relates to a pipeline replacement planning support system and a pipeline replacement planning support method, and more specifically to a technique that supports designing an optimal replacement plan for pipelines minimizing life-cycle cost of the pipelines.

Background Art

[0002]

With respect to various types of pipes including water distribution pipes constituting a water supply system and the like, the probability of occurrence of such problems as frequent water leakage and degradation of water quality distributed increases as the pipes age. Therefore, it is desirable to replace the pipes at appropriate intervals. Since such replacement obviously requires resources such as a budget and manpower, suitable administrative entity is in charge of coming up with a replacement plan.

[0003]

As related art regarding establishment of a pipeline replacement plan, such a technique is proposed as dividing a distributing area into a plurality of meshes, obtaining a water leakage amount in each mesh, and improving efficiency in establishment of a pipeline replacement plan by utilizing the information thus obtained. See Japanese Patent Application Laid-open Publication No. 2009-192329, for example. Another

technique is proposed in Japanese Patent Application Laid-open Publication No. 2005-114582 such as identifying a pipeline in which water leakage due to aging is likely by investigating aging of a distribution block using real time frequency analysis of measured pressure and flow rate values to improve efficiency of a pipeline replacement plan. Further, a technique is proposed such as determining a cycle period for investigating water leakage that minimizes an annual cost provided by a sum of loss due to water leakage and an investigation cost. See, for example, "Recent Advances in Calculation Economic Intervention Frequency for Active Leakage Level," IWA International Conference on Water Economics, Statistics, and Finance, Rethymno, Greece, 8-10 July 2005, for example.

[0004]

Although effective to a certain extent in improving the efficiency of designing a pipeline replacement plan, the related art does not take certain elements into consideration, such as replacement intervals, intervals between inspections for leakage, and life-cycle cost. Consequently, the information required for establishing an optimal pipeline replacement plan that truly minimizes pipeline life-cycle cost is unavailable.

[0005]

SUMMARY

The present invention provides a pipeline replacement planning system and method that supports designing an optimal replacement plan for pipelines that minimizes life-cycle cost.

[0006]

In order to solve the above and other problems, one aspect of the present invention is a support system for designing a pipeline replacement plan having a storage device and a processor. The storage device is configured to store

cost calculation information including pipe attribute information. The processor is configured to calculate replacement introduction cost required for replacing water distribution pipes and maintenance cost of water distribution pipes caused by water leakage in the water distribution pipes based on information for cost calculation; calculate a life-cycle cost of the water distribution pipes using the calculated replacement introduction cost and maintenance cost; calculate an optimal replacement timing of the water distribution pipes that minimizes the calculated life-cycle cost; and display, on an output device, the calculated replacement introduction cost, maintenance cost, life-cycle cost, and the optimal replacement timing for the water distribution pipes.

[0007]

Also disclosed is a method of supporting design of a pipeline replacement plan implemented by a computer including a storage device configured to store cost calculation information including pipe attribute information and a processor. The computer calculates replacement introduction cost required for replacing water distribution pipes and maintenance cost of water distribution pipes caused by water leakage in the water distribution pipes based on information for cost calculation, calculates a life-cycle cost of the water distribution pipes using the calculated replacement introduction cost and maintenance cost, calculates an optimal replacement timing of the water distribution pipes that minimizes the calculated life-cycle cost, and displays, on an output device, the calculated replacement introduction cost, maintenance cost, life-cycle cost, and the optimal replacement timing for the water distribution pipes.

[0008]

According to the aspects of the present invention, a pipeline replacement planning system and method that supports

designing an optimal replacement plan for pipelines that minimizes life-cycle cost are provided.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009]

Fig. 1 is a diagram showing an example of configuration of a pipeline replacement planning support system according to a first embodiment of the present invention;

Fig. 2 is a diagram showing an example of pipeline information stored in a cost calculation information database in the first embodiment;

Fig. 3 is a diagram showing a configuration of a water distribution pipeline as a replacement target in the first embodiment;

Fig. 4 is a diagram showing an example of change over time in amount of water leaking from a water distribution pipe;

Fig. 5 is a diagram showing an example of change over time in amount of water leaking from a water distribution pipe where sufficient repairs are not made;

Fig. 6 is a diagram showing an example of a relationship between various costs and replacement intervals in a water distribution pipeline;

Fig. 7 is a diagram showing steps in a process executed by a pipeline replacement planning support system of the first embodiment;

Fig. 8 is a diagram showing an example of configuration of a pipeline replacement planning support system according to a second embodiment of the present invention;

Fig. 9 is a diagram showing change over time in amount of water leaking from a service pipe;

Fig. 10 is a diagram showing an example of a data structure of a cost calculation information database in the second embodiment;

Fig. 11 is a diagram showing an example of relationship between service pipe inspection interval and various costs;

Fig. 12 is a diagram showing an example of a relationship between a replacement time interval of a water distribution pipeline and various costs;

Fig. 13 is a diagram showing an exemplary result of various costs dependent on water leakage inspection intervals and optimal intervals for replacement of water distribution pipes;

Fig. 14 is a diagram showing steps in a process executed by the pipeline replacement planning support method according to the second embodiment;

Fig. 15 is a diagram showing number of water distribution pipelines replaced and replacement cost of each year with optimal replacement timing and setting an upper limit to the replacement cost of each year according to a third embodiment of the present invention;

Fig. 16 is a diagram showing an example of replacement cost of each pipeline as a replacement target in the third embodiment;

Fig. 17 is a diagram showing an example of a pipeline as a replacement target and replacement cost of each year where replacement is made according to an optimal replacement timing calculated according to the method of the first embodiment;

Fig. 18 is a diagram showing an example of a pipeline as a replacement target and a replacement cost of each year where an upper limit is set to the replacement cost calculated according to the method of the third embodiment;

Fig. 19 is a diagram showing an example of characteristics of a life-cycle cost of a water distribution pipeline; and

Fig. 20 is a diagram showing steps in a process executed by the pipeline replacement planning support method according to the third embodiment.

DETAILED DESCRIPTION

[0010]

First Embodiment

A first embodiment of the present invention will be described in detail referring to Figs. 1-7 hereinbelow.

Fig. 1 is a diagram showing an example of a configuration of a pipeline replacement planning support system according to the first embodiment. The pipeline replacement planning support system 100 is a computer system that supports designing an optimal replacement plan for pipelines that minimizes life-cycle cost (LCC) of the pipelines.

[0011]

A hardware configuration of the pipeline replacement planning support system 100 is as follows. The pipeline replacement planning support system 100 includes a storage device 101 configured with a suitable non-volatile storage device such as a hard disk drive, a memory 103 configured with a volatile storage device such as a RAM, a processor 104 such as a CPU for overall control of the system and various determination, operation, and control processing by loading a program 102 stored in the storage device 101 into the memory 103 and executing the same, an input device 105 for accepting various key inputs and audio inputs corresponding to an instruction for starting a calculation, designation of contents to be output and the like, and an output device 106 such as a display for displaying processing data. The input device 105 may be or may include a network interface receiving data from an external network. It is to be noted that the storage device 101 stores at least the program 102 for implementing functions required for the pipeline replacement planning support system 100 of the present embodiment and information for calculating costs, that is, information stored in a cost calculation information database 125.

[0012]

The cost calculation information database 125 stored in the storage device 101 is a database storing attribute information for each water distribution pipeline classified in advance. In the first embodiment, a configuration including water distribution pipelines 41-44 as illustrated in Fig. 3 is assumed. In the configuration in Fig. 3, it is also assumed that each water distribution pipeline 41-44 is configured by connecting pipes of the same type and the same diameter, and the pipelines are the same age since installation. A length of each pipeline is assumed to range from several hundred meters to several tens of kilometers. In the exemplary diagram in Fig. 3, a circle stands for a connecting point of the water distribution pipelines 41-44. It is assumed that a plurality of service pipes 401 are connected to each of the water distribution pipelines 41-44.

[0013]

As shown in Fig. 2, the cost calculation information database 125 is a set of records having an identification number for the water distribution pipelines as a key correlated with attribute data regarding the water distribution pipelines including pipeline length, diameter, pipe type, time of use, number of repairs, information on ground, inspection cycle for water leakage, specifications, structurally unavoidable water leakage amount, and optimal replacement timing. Here, all the attribute data except the optimal replacement timing is set in advance by a user, that is, a planner of a pipeline replacement plan. On the other hand, the optimal replacement timing is calculated automatically by the pipeline replacement planning support system 100 according to the calculations described later and set in a corresponding field of the database 125. The cost calculation information database 125 stores calculation results for various costs described later.

[0014]

Next, functional units of the pipeline replacement planning support system 100 in the first embodiment will be described. As described above, the functional units below are implemented by executing the program 102 in the pipeline replacement planning support system 100.

[0015]

In the pipeline replacement planning support system 100, a water distribution pipeline introduction cost calculation unit 111, a water distribution pipeline maintenance/management cost calculation unit 112, a water distribution pipeline LCC calculation unit 113, and an optimal replacement timing calculation unit 114 are installed. In the above units, the water distribution pipeline introduction cost calculation unit 111 converts a cost CI of replacing old water distribution pipes constituting each water distribution pipeline with new pipes into a cost CI_0 required for each year. Here, replacement cost of the water distribution pipes includes the cost of public works projects for replacement of the pipes and materials cost of the pipes. The cost required for each year can be calculated according to the formula below, for example:

[0016]

$$CI_0 = CI \cdot \frac{i}{1-(1+i)^{-n}}$$

$$CI = L \cdot (4 + 6\frac{D}{200}) \quad \cdots\cdots \text{Formula 1}$$

[0017]

Here, CI_0 is the cost of introducing water distribution pipes each year, CI is the cost of introducing water distribution pipes, n is a replacement cycle in years correlated with the age in years of the water distribution pipeline, i is capital cost, L is the length of the water distribution pipeline in meters, and D is the diameter of the water distribution pipe. It is to be noted that the cost may

be set taking into consideration the type of pipes in Formula 1. The water distribution pipe introduction cost calculation unit 111 calculates the water distribution pipe annual introduction cost CI_0 for different replacement cycles n to which a calculation range is set via the input device 105 for example, for each water distribution pipeline using the above formula, and stores the results correlated with the corresponding water distribution pipeline in the cost calculation information database 125.

[0018]

The water distribution pipe maintenance/management cost calculation unit 112 is configured to calculate a running cost required for maintenance/management of a water distribution pipeline and convert the result into an annual cost. The running cost mainly includes the cost of addressing water leakage accidents CR, the cost of water leakage loss caused by the water leakage left without repair CL, and the like. The other costs includes the cost of compensation for damage due to accidents, manpower cost of addressing accidents and so on, which may be considered in calculating the cost. The cost of addressing water leakage accidents means the cost necessary for repairing a portion where water leakage has occurred, which is calculated by the water distribution pipe maintenance/management cost calculation unit 112 using the formula below:

[0019]

$$CR(t) = CR_0 \cdot N_A(t)$$

$$CR_0 = 50 \cdot \frac{D}{200} \qquad \cdots\cdots \text{Formula 2}$$

$$N_A(t) = L \cdot N(t)$$

[0020]

Here, CR(t) is the cost of addressing a water leakage accident in the "t"th year, CR_0 is the cost of a single accident, $N_A(t)$ is the number of accidents in "t"th year, N(t)

is the number of water leakage accidents in the "t"th year per unit length of a pipeline, D is the diameter of a water distribution pipeline as a target of replacement in millimeters, L is the length of a pipeline as a target of replacement in meters, and t is the number of years in use. In the above variables, for the number of accidents, the actual values stored in the cost calculation information database 125 are used if available. For the number of future accidents where no actual value is available, expected values are used which are calculated through Formulas 3 and 4 using the attribute information stored in the records in the cost calculation information database 125.

[0021]

$$N(t) = C_1 \cdot C_2 \cdot C_3 \cdot F_m(t) \quad \cdots\cdots \text{Formula 3}$$

$$F_{DIP}(t) = 0.0007e^{0.0758t}$$

$$F_{SP}(t) = 0.0074e^{0.0618t} \quad \cdots\cdots \text{Formula 4}$$

$$F_{VP}(t) = 1.27 \times 10^{-5} \cdot t^{2.907}$$

$$F_{CIP}(t) = 1.91 \times 10^{-12} \cdot t^{6.502}$$

[0022]

Here, N(t) is an expected value for the number of water leakage accidents per unit pipeline length in the "t"th year, $F_m(t)$ is an expected value for the number of water leakage accidents per unit length of a pipeline of the type m in the "t"th year, C_1 is a specifications-related compensation coefficient, C_2 is a diameter compensation coefficient, C_3 is a ground condition compensation coefficient. The pipe type m includes DIP, SP, VP, and CIP. Regarding C1, the specifications include presence/absence of a polyethylene sleeve, a welded joint, a screw joint, a TS joint, a RR joint, or the like. Formula 4 can be seen in "Study on Pipeline Technology for Sustainable Water Service," a report published by the Japan Water Research Center.

[0023]

Next, a method of calculating the cost of water leakage loss CL(t) caused by water leakage left unrepaired will be described.

In general, water leakage is classified into ground leakage, which appears on the ground, and underground leakage, which does not appear on the ground. Ground leakage can be discovered through notification from nearby residents or the like and can be addressed quickly. However, an underground leak can only be found through periodic inspectioninspection to address the same. In other words, underground leakage is left unaddressed until the next inspection is performed. Fig. 4 shows an example of a time change of an amount of underground water leaking from a water distribution pipeline. The broken line 23 in Fig. 4 stands for an unavoidable amount of water leaking from a water distribution pipeline which can be calculated using the formula below:

[0024]

$$UARL_d(\ell/day) = 18 \cdot Lm \cdot P \quad \cdots\cdots \text{Formula 5}$$

[0025]

Here, UARL_d is an unavoidable water leakage amount in liters per day, Lm is the total length of a water distribution pipeline as a target in kilometers, and P is the average water pressure in a water distribution pipeline as a target in meters. A numeric value substituted into either variable is stored in the cost calculation information database 125 in advance or is received through the input device 105 for calculation. The broken line 21 in Fig. 4 stands for a change in water leakage amount over time where neither inspections nor repairs are made regarding underground leakage, which is calculated with the following formula:

[0026]

$$Q_B(t) = Q_0 + \sum_{t=0}^{t} k \cdot N_A(t) \cdot S \cdot P^{0.5} \quad \cdots\cdots \text{Formula 6}$$

[0027]

Here, $Q_B(t)$ is an underground water leakage amount, Q_0 is an unavoidable water leakage amount in a target water distribution pipeline, k is the ratio of underground leakage to the total water leakage amount such as 0.1, $N_A(t)$ is the number of underground leakages in the "t"th year in a target water distribution pipeline, S is average crack area in a single water leakage, and P is average water pressure. A numeric value substituted into any of these variables is stored in the cost calculation information database 125 in advance or is received through the input device 105 upon calculation. In the above formula, $S \cdot P^{0.5}$ is an underground water leakage amount per a single water leakage accident. If the amount value is known, the known value may be used in place of $S \cdot P^{0.5}$.

[0028]

Note that in Fig. 4 T_0 is an inspection cycle and the broken line 22 represents a response of the water leakage amount in the event that all underground leakages are found during inspection and repaired. The response of the water leakage amount indicated by the broken line 22 can be calculated as follows:

[0029]

Where $nT_0 \le t < (n+1)T_0$

$$Q_B(t) = Q_0 + \sum_{t=0}^{t} k \cdot N_A(t) \cdot S \cdot P^{0.5} - \sum_{t=0}^{nT_0} k \cdot N_A(t) \cdot S \cdot P^{0.5} \quad \cdots\cdots \text{Formula 7}$$

[0030]

Here, T_0 is the inspection cycle in years and n is an integer equal to or larger than 0. Repair of the water

leakage parts decreases the water leakage amount in a water distribution pipeline to the level of the unavoidable water leakage amount 23. However, since the water distribution pipeline continues to deteriorate over time, a speed of water leakage increase up to the water leakage level before repair gradually increases. Referring to Fig. 4, it can be appreciated that the average water leakage amount increases over time. The water distribution pipe maintenance/management cost calculation unit 112 calculates the cost of loss by water leakage in a target water distribution pipeline in the "t"th year after installation of the same using an underground water leakage amount $Q_B(t)$ where water inspection/repair calculated by Formula 7 is performed according to the following formula:

[0031]

$$C_L(t) = C_{L0} \cdot Q_B(t) \quad \cdots\cdots \text{Formula 8}$$

[0032]

Here, $C_L(t)$ is the cost of water leakage loss in the "t"th year after installation of the pipeline, and CL_0 is the cost of producing a unit water. A numeric value substituted into either variable is stored in the cost calculation information database 125 in advance or is received through the input device 105 upon calculation. The change over time in the underground water leakage amount in Fig. 4 is used as one of the models 115 for calculating the cost of water leakage loss.

[0033]

Fig. 5 shows an a example of change in water leakage amount over time where not all underground water leakage are found/repaired. The water leakage amount 21 where water inspection/repairs are not carried out and the unavoidable water leakage amount 23 are the same as those in Fig. 4. On the other hand, the water leakage amount 32 where inspection/repairs are made is larger than the water leakage

amount 22 in Fig. 4 since the water leakage amount 32 does not decrease to the level of the unavoidable water leakage amount 23 completely. A blackened circle 34 in Fig. 5 indicates a water leakage amount at the timing of inspection/repair which is represented by ΔQ. The water leakage amount ΔQ is calculated using cumulative water leakage repair record according to the following formula:

[0034]

$$\Delta N(t) = \sum_{t=0}^{t} (N_A(t) - N_r(t))$$
$$\Delta Q(t) = Q_0 + k \cdot \Delta N(t) \cdot S \cdot P^{0.5} \quad \cdots\cdots \text{Formula 9}$$
$$t = nT_0 (N = 0, 1, 2, ...)$$

[0035]

Here, $N_A(t)$ is the number of water leakage accidents in the "t"th year, $N_r(t)$ is the number of repairs of water leakage accidents in the "t"th year, and ΔN(t) is the total number of unrepaired water leakages up to the "t"th year. A numeric value substituted into any of these variables is stored in the cost calculation information database 125 in advance or is received through the input device 105 upon calculation.

[0036]

Further, the water leakage amount 32 where water inspection/repairs are made is calculated using the following formula:

[0037]

$$Q_{B2}(t) = Q_0 + \Delta Q(nT_0) + \sum_{t=0}^{t} k \cdot N_A(t) \cdot S \cdot P^{0.5} \quad \cdots\cdots \text{Formula 10}$$
$$- \sum_{t=0}^{nT_0} k \cdot N_A(t) \cdot S \cdot P^{0.5}$$

[0038]

Here, $Q_{B2}(t)$ is the water leakage amount where the leak cannot be completely repaired.

[0039]

The cost of water leakage loss $C_L(t)$ in this case can be calculated according to the following formula:

[0040]

$$C_L(t) = C_{L0} \cdot Q_{B2}(t) \quad \cdots\cdots \text{Formula 11}$$

[0041]

Using the cost of addressing water leakage accidents in the "t"th year $C_R(t)$ according to Formula 2, Formula 8, and the cost of water leakage loss $C_L(t)$ in the "t"th year according to Formula 11, a water distribution pipeline maintenance/management cost $C_M(t)$ can be calculated according to the following formula:

[0042]

$$C_M(t) = C_R(t) + C_L(t) \quad \cdots\cdots \text{Formula 12}$$

[0043]

The water distribution pipe maintenance/management cost calculation unit 112 calculates the water distribution pipe annual maintenance/management cost C_{M0} for different replacement cycles n, in years, to which a calculation range is set via the input device 101, for example, for each water distribution pipeline using $C_M(t)$ in Formula 12, and stores the results correlated with the corresponding water distribution pipeline in the cost calculation information database 125.

[0044]

$$C_{M0} = \left(\sum_{t=1}^{n} \frac{C_M(t)}{(1+i)^t} \right) \cdot \frac{i}{1-(1+i)^{-n}} \quad \cdots\cdots \text{Formula 13}$$

[0045]

Here, C_{M0} is the annual water distribution pipe maintenance/management cost, n is the replacement cycle in years, i is capital cost, and $C_M(t)$ is maintenance/management cost in the "t"th year. Formula 8 or Formula 11 is one of the models 115 for calculating the cost of water leakage loss.

[0046]

Next, the water distribution pipe LCC calculation unit 113 and the optimal replacement timing calculation unit 114 will be described. The water distribution pipe LCC calculation unit 113 calculates the water distribution pipe annual LCC for different replacement cycles n in years to which a calculation range is set via the input device 105 for example, for each water distribution pipeline using the following formula derived from Formulas 2 and 13, and stores the results in a corresponding record in the cost calculation information database 125.

[0047]

$$\text{WATER DISTRIBUTION PIPE LCC} = \left(C_I + \sum_{t=1}^{n} \frac{C_M(t)}{(1+i)^t}\right) \cdot \frac{i}{1-(1+i)^{-n}} \quad \cdots\cdots \text{Formula 14}$$

[0048]

The optimal replacement timing calculation unit 114 identifies a replacement timing n that minimizes the water distribution pipe LCC calculated by the water distribution pipe LCC calculation unit 113 as above, and stores the identified replacement timing in a replacement timing field in the corresponding record in the cost calculation information database 125.

[0049]

Each calculation in the pipeline replacement planning support system 100 as described above is carried out for each water distribution pipeline 41-44 in Fig. 2 and the annual water distribution pipeline introduction cost, the water distribution pipeline maintenance/management cost, the water distribution pipeline LCC and the optimal replacement timing calculated are all stored in the cost calculation information database 125.

[0050]

The pipeline replacement planning support system 100

displays the results of each calculation as described above on the output device 106. Fig. 6 shows an example of the output result indicating an exemplary relationship between each cost related to the water distribution pipeline and the replacement timing. In the example shown here, there is a trade-off between the pipeline introduction cost 61 and the pipeline maintenance/management cost 62, and the water distribution pipe LCC 63 as the sum of the costs 61 and 62 is defined by a downwardly convex curve that has a minimum value. In Fig. 6, the replacement timing that minimizes the water distribution pipe LCC is the optimal replacement timing. The pipeline replacement planning support system 100 performs the above respective calculations for each water distribution pipeline 41-44 illustrated in Fig. 2, generates the graph illustrated in Fig. 6 based on the calculation results, and displays the graph on the output device 106. Note that although calculations are done for four pipelines in this embodiment, typically these calculations are performed for many more water distribution pipelines (several hundred to several thousand), in which case the above calculations are done for all the water distribution pipelines. Additionally, the pipeline replacement planning support system 100 may be configured to display information (in which the optimal replacement timing value is set) stored in the cost calculation information database 125 through the output device 106 and/or output the information in the form of an electronic file other than the calculation result as the graph in Fig. 6.

[0051]

Actual processes of the pipeline replacement planning support method according to the first embodiment will be described referring to the drawings. Various operations corresponding to the pipeline replacement planning support method to be described below are implemented by programs loaded into the memory and the like and executed by the

pipeline replacement planning support system 100. The programs are constructed with program code for performing various operations described below.

[0052]

Fig. 7 is a diagram showing steps in a process executed by a pipeline replacement planning support method of the first embodiment. First, the pipeline replacement planning support system 100 sets "1" as a variable N corresponding to the pipeline number in the memory 103 (step 701). Subsequently, the pipeline replacement planning support system 100 determines if an optimal replacement timing is calculated for all the water distribution pipelines (step 702). Since the pipeline replacement planning support system 100 calculates the optimal replacement timing for each water distribution pipeline in the cost calculation information database 125 and sets the calculation result in the "optimal replacement timing" field, it can be determined that the calculation of the optimal replacement timing is not completed for all the water distribution pipelines, if there exists any water distribution pipeline for which no value is stored in the "optimal replacement timing" field in the cost calculation information database 125.

[0053]

If it is confirmed that the calculations for all the water distribution pipelines are not yet completed as a result of the determination in step 702 above (step 702: N), the process proceeds to step 703 and the following steps. On the other hand, if it is confirmed that the calculations for all the water distribution pipelines are completed as a result of the determination in step 702 above (step 702: Y), the process proceeds to step 709.

[0054]

If it is confirmed that the calculations for all the water distribution pipelines are not yet completed (step 702:

N), the pipeline replacement planning support system 100 reads attribute data of the target pipeline, i.e., the water distribution pipeline N for which the calculation of the optimal replacement timing is not yet completed, from the corresponding record in the cost calculation information database 125. The attribute data includes pipeline length, diameter, pipe type, and the like, required for various calculations (step 703).

[0055]

Subsequently, the water distribution pipe introduction cost calculating unit 111 of the pipeline replacement planning support system 100 applies the attribute data retrieved in step 703 to the aforementioned Formula 1 and calculates water distribution pipe introduction costs for various replacement intervals (step 704). Needless to say, the water distribution pipe introduction cost calculating unit 111 is configured in advance with a formula corresponding to Formula 1 necessary for these calculations. This assumption also holds for the other functional units and the other formulas. The procedure for calculating the water distribution pipe introduction cost used in Formula 1 is the same as described above.

[0056]

Subsequently, the water distribution pipe maintenance/management cost calculating unit 112 of the pipeline replacement planning support system 100 applies the attribute data retrieved in step 703 to the aforementioned Formula 13 and calculates water distribution pipe maintenance/management costs for various replacement intervals (step 705). The procedure for calculating the water distribution pipe maintenance/management cost used in Formula 13 is the same as described above.

[0057]

Subsequently, the water distribution pipe LCC calculating unit 113 of the pipeline replacement planning support system

100 calculates water distribution pipe LCCs for various replacement intervals according to Formula 14 (step 706). The procedure for calculating the water distribution pipe LCC used in Formula 14 is the same as described above.

[0058]

Having received the calculation result of the water distribution pipe LCC in step 706, the optimal replacement timing calculation unit 114 identifies the replacement timing that minimizes the water distribution pipe LCC as an optimal replacement timing based on the calculation result (step 707). This processing is done by identifying the replacement timing that minimizes the water distribution pipe LCC 63 in the graph illustrated in Fig. 6.

[0059]

As described above, when the calculation of the optimal replacement timing is completed for a target water distribution pipeline, the optimal replacement timing calculation unit 114 of the pipeline replacement planning support system 100 increments the value "N" set in the memory 103 in step 701 by 1 (step 708), and the process returns to step 702.

[0060]

The pipeline replacement planning support system 100 repeats step 702 to step 708 above until the calculation of the optimal replacement timing is completed for all the water distribution pipelines. When the calculation of the optimal replacement timing is completed for all the water distribution pipelines (step 702: Y), the pipeline replacement planning support system 100 stores the values for the optimal replacement intervals for the respective water distribution pipelines in the corresponding records in the cost calculation information database 125, displays the resulting values on the output device 106 (step 709), and ends the process.

[0061]

It is to be noted that when the pipeline replacement planning support system 100 displays the calculation results on the output device 106, the pipeline replacement planning support system 100 may accept a format designation input through the input device 105, for example, generate screen data by setting the calculation results in a template corresponding to the above format which may be held in the storage device 101 in advance, and display the screen data on the output device 106. An example of the display may be the graph indicating the optimal replacement intervals in the mutual relationship between introduction, maintenance/management, and replacement timing for a water distribution pipeline as shown in Fig. 6.

[0062]

Second Embodiment

Next, a second embodiment of the present invention will be described with reference to Figs. 8-14.

In the second embodiment, a technology is described that takes into account maintenance/management cost for service pipes in addition to water distribution pipelines to more precisely identify an optimal replacement timing and an optimal inspection timing of water distribution pipelines.

Fig. 8 is a diagram showing an example of a configuration of a pipeline replacement planning support system 100 according to the second embodiment of the present invention. In the system 100, the memory 103, the arithmetic unit 104, the input device 105, the output device 106, the cost calculation information database 125, and the water distribution pipe introduction cost calculation unit 111 and the water distribution maintenance/management cost calculation unit 112 in the storage device 101 are the same as those in the first embodiment.

[0063]

On the other hand, the pipeline replacement planning

support system 100 of the second embodiment also includes a service pipe maintenance/management cost calculation unit 116. In addition, the pipeline replacement planning support system 100 of the second embodiment does not include the water distribution pipe LCC calculation unit 113 and the optimal replacement timing calculation unit 114 but instead includes a total pipeline LCC calculation unit 117 and an optimal replacement timing/optimal inspection cycle calculation unit 118.

[0064]

The pipeline replacement planning support system 100 of the second embodiment thus constructed is configured to calculate a total LCC obtained by adding a service pipe LCC, i.e., a service pipe maintenance/management cost to the water distribution pipe LCC, and seek the water distribution pipeline replacement timing and the water inspection cycle that minimizes the total LCC. Hereinafter, the parts of the second embodiment different from the construction and the processing of the first embodiment will be described.

[0065]

In the functional units provided with the pipeline replacement planning support system 100 of the second embodiment, the service pipe maintenance/management cost calculation unit 116 is a functional unit configured to calculate a maintenance/management cost of service pipes connected to each water distribution pipeline. The calculation of the service pipe maintenance/management cost in the service pipe maintenance/management cost calculation unit 116 will be described referring to Fig. 9.

[0066]

Fig. 9 is a diagram showing change over time in the amount of water leaking from all the service pipes connecting to a water distribution pipeline, such as the water distribution pipeline 41 among the water distribution

pipelines shown in Fig. 3. Ordinarily, various pipes from new ones to old ones are connected to each water distribution pipeline, and the degree of obsolescence between service pipes connected to a water distribution pipeline is taken to be a uniform value. In this case, a water leakage increase speed of the service pipes becomes a constant velocity V. The exact value of the velocity V is estimated based on past record of water leakage. Under these circumstances, underground water leakage of the service pipes is repaired at the intervals of water inspection for the water distribution pipeline performed every inspection cycle T_0 as with the water distribution pipeline. Thus, a water leakage amount 92 decreases down to the level of an unavoidable water leakage amount 93 at the inspection intervals. However, thereafter, water leakage again appears due to deterioration of the service pipes over time and the water leakage amount 92 linearly increases at the speed V. Such an event occurs repeatedly at the inspection intervals. It is to be noted that the water leakage amount 91 continuously increases at the constant velocity V without decreasing toward the unavoidable water leakage amount 93 in the event that inspection and repair are not carried out.

[0067]

The service pipe maintenance/ management cost calculation unit 116 calculates an unavoidable amount of water leakage from the service pipes connected to a water distribution pipeline according to the following formula:

[0068]

$$UARL_s(\ell/day) = (0.8 \cdot Nc + 25 \cdot Lc) \cdot P \quad \cdots\cdots \text{Formula 15}$$

[0069]

Here, N_C is the number of service pipe removals, L_C is the total length of the service pipes connected to a target water distribution pipeline in kilometers, and P is the average pressure in the target water distribution pipeline in meters.

A numeric value substituted into any of these variables is stored in the cost calculation information database 125 in advance or is received through the input device 105 upon calculation. It is to be noted that the cost calculation information database 125 in the second embodiment has a data structure in which attribute information for the service pipes connected to each water distribution pipeline is stored correlated with a record of the corresponding water distribution pipeline as shown in Fig. 10.

[0070]

The service pipe maintenance/management cost calculation unit 116 calculates an annual average water leakage amount Ql_S for a period T_0 from the service pipes connected to the corresponding water distribution pipeline based on the graph in Fig. 9 as a water leakage loss calculation model 115 according to the following formula:

[0071]

$$Qls = UARL_s + \frac{1}{2}VT_0 \quad \cdots\cdots \text{Formula 16}$$

[0072]

Here, V is a water leakage increase speed in m^3/year.

[0073]

Further, the service pipe maintenance/management cost calculation unit 116 calculates the cost of annual loss Cl_S due to water leakage from the service pipes connected to the corresponding water distribution pipeline according to the following formula:

[0074]

$$C_{ls} = C_{L0} \cdot Q_{ls} \quad \cdots\cdots \text{Formula 17}$$

[0075]

Here, C_{L0} is the cost of producing unit water in yen/m^3.

[0076]

On the other hand, the service pipe maintenance/management cost calculation unit 116 calculates an annual average inspection cost of inspecting water leakage in the water distribution pipeline and the service pipes connected thereto from the above inspection cycle T_0 according to the following formula:

[0077]

$$C_{is} = L\frac{C_{is0}}{T_0} \quad \cdots\cdots \text{Formula 18}$$

[0078]

Here, C_{is0} is the cost of inspection per unit length of water distribution pipe, L is total length of a target water distribution pipes, and T_0 is inspection cycle.

[0079]

Subsequently, the service pipe maintenance/management cost calculation unit 116 calculates a service pipe maintenance/management cost, i.e., a service pipe LCC, according to the following formula that is a sum of the above Formula 17 and Formula 18:

[0080]

$$\text{WATER SUPPLY PIPE LCC} = C_{L0}(UARL_s + \frac{1}{2}VT_0) + L\frac{C_{is0}}{T_0} \quad \cdots\cdots \text{Formula 19}$$

[0081]

The service pipe maintenance/management cost calculation unit 116 calculates service pipe LCCs for various inspection cycles according to Formula 19 above, and stores the calculation result in a record of the corresponding water distribution pipe in the cost calculation information database 125.

[0082]

Hereafter, referring to Figs. 11 and 12, the significance of calculating a total life-cycle cost as the sum of a water

distribution pipe LCC and a service pipe maintenance/management cost, i.e., a service pipe LCC, and calculating a water distribution pipeline replacement timing and a water inspection cycle that minimize the total life-cycle cost will be described.

[0083]

Fig. 11 shows a graph of a water leakage loss cost C_{ls}, an inspection cost C_{is}, and an annual service pipe LCC, i.e., a service pipe maintenance/management cost calculated according to Formulas 17, 18 and 19 above, respectively, as a function of an inspection cycle T0 drawn by the pipeline replacement planning support system 100. In the graph, the water leakage loss cost C_{ls}, the inspection cost C_{is}, and the annual service pipe LCC are indicated by lines 83, 82, and 81, respectively.

[0084]

According to the graph in Fig. 11, it can be appreciated that inspection cycle 84 is the one that minimizes the service pipe LCC 81. In the pipeline replacement planning support system 100, a water distribution pipeline maintenance/management cost 1103A is calculated using the above inspection cycle 84, and then, an annual water distribution pipe LCC 1101A and an optimal replacement timing 1104A are calculated. The respective calculation results are drawn in the graph of Fig. 12 as the respective broken lines.

[0085]

In the event that the inspection cycle is set to a period shorter than the inspection cycle 84 obtained in Fig. 11, the water distribution pipe maintenance/management cost is reduced from the solid line 1103A to the broken line 1103B as shown in Fig. 12. At this time, the water distribution pipe LCC 1101A is moved to the water distribution pipe LCC 1101B shown in Fig. 12 as a broken line. When the water inspection cycle 84 is made shorter in the graph in Fig. 11, the service pipe LCC 81 increases. However, at the same time, in the graph of Fig.

12, the water distribution pipe maintenance/management cost 1103A is reduced to the cost 1103B shown by a broken line and the water distribution pipe LCC with the minimum value thereof is reduced from the solid line 1101A to the broken line 1101B. Therefore, it can be appreciated that the inspection cycle that minimizes the total life-cycle cost defined as the sum of the minimum value of the water distribution pipe LCC and the service pipe LCC may be different from the optimal inspection cycle in Fig. 11. This means that the life-cycle cost can be further reduced by obtaining the water distribution pipeline replacement timing and the inspection cycle minimizing the total life-cycle cost.

[0086]

Accordingly, the total pipeline LCC calculation unit 117 of the pipeline replacement planning support system 100 of the second embodiment calculates the service pipe LCC according to Formula 19 above, calculates the water distribution pipe LCC and the minimum value thereof according to Formula 14 above, and calculates the total LCC by adding the water distribution pipe LCC to the minimum value thereof to the service pipe LCC, for different inspection cycle times. In the course of the above calculations, the water distribution pipeline replacement timing minimizing the water distribution pipe LCC is also calculated. An example of the calculation result is shown in Fig. 13. Referring to the calculation result, the optimal replacement timing/optimal inspection cycle calculation unit 118 calculates the water distribution pipeline replacement timing and the inspection cycle minimizing the total LCC as the sum of the service pipe LCC and the water distribution pipe LCC and the minimum value thereof.

[0087]

The total pipeline LCC calculation unit 117 of the pipeline replacement planning support system 100 calculates

the total pipeline LCC as the life-cycle cost by adding the service pipe LCC as the service pipe maintenance/management cost obtained at the service pipe maintenance/management cost calculation unit 116 to the calculated water distribution pipe LCC. Either the total pipeline LCC calculation unit or the optimal replacement timing/optimal inspection cycle calculation unit 118 sets the above calculation result in the format of the table 1300 in Fig. 13 and displays the result through the output device 106. Since an inspection cycle that minimizes the total pipeline LCC is considered optimal, in the calculation result in the table 1300, "Case 2" shown as a shaded part 1301, that is, "3 years" of the inspection cycle is optimal, and the optimal water distribution pipe replacement cycle is "85 years." The pipeline replacement planning support system 100 stores the above calculation result in the cost calculation information database 125.

[0088]

An actual pipeline replacement planning support method according to the second embodiment will be described referring to the drawings as in the first embodiment.

Fig. 14 is an example of steps in the pipeline replacement planning support method according to the second embodiment. First, the pipeline replacement planning support system 100 accepts input designation of an interval of the inspection cycle (step 1300). Here, the interval is assumed to be 1 year.

[0089]

Subsequently, the pipeline replacement planning support system 100 sets "1" for a variable N corresponding to the number of pipelines in the memory 103 (step 701). Further, the pipeline replacement planning support system 100 determines if calculations are completed for all the water distribution pipelines (step 702). This determination process is the same as in the first embodiment.

[0090]

If it is confirmed that the calculations for all the water distribution pipelines are not yet completed as a result of the determination in step 702 above (step 702: N), the process proceeds to step 1301 and the following steps. On the other hand, if it is confirmed that the calculations for all the water distribution pipelines are completed as a result of the determination in step 702 above (step 702: Y), the process proceeds to step 1307.

[0091]

The pipeline replacement planning support system 100 reads attribute data of the target pipeline, i.e., the water distribution pipeline N from the corresponding record in the cost calculation information database 125 (step 1301). In the second embodiment, the inspection cycle is also a target of identification. Therefore, the information for the inspection cycle is not yet stored in the cost calculation information database 125 before this method is fully executed.

[0092]

Subsequently, the service pipe maintenance/management cost calculating unit 116 of the pipeline replacement planning support system 100 applies each piece of attribute data and the like retrieved in step 1301 to the aforementioned Formula 19 and calculates service pipe maintenance/management costs, i.e., service pipe LCCs for various inspection cycles (step 1302). Meanwhile, as in the first embodiment, the water distribution pipe introduction cost calculating unit 111 applies the attribute data of the corresponding water distribution pipeline to Formula 1 and calculates the water distribution pipe introduction costs for various replacement cycles (step 704).

[0093]

Next, as in the first embodiment, the water distribution pipe maintenance/management cost calculation unit 112

calculates the water distribution pipe maintenance/management costs for various replacement cycles and inspection cycles using Formula 13 (step 1303).

[0094]

The total pipeline LCC calculation unit 117 calculates the water distribution pipe LCC for various replacement cycles and inspection cycles and also obtains the replacement timing that minimizes water distribution pipe LCC (step 1304). Further, the total pipeline LCC calculation unit 117 calculates the total LCCs for various inspection cycles by adding the minimum value of the water distribution pipe LCC obtained in step 1304 to the service pipe LCC obtained in the above step 1302 (step 1305). Through the above calculations, the calculation result illustrated in Fig. 13 as an example is obtained.

[0095]

Subsequently, the optimal replacement timing/optimal inspection cycle calculation unit 118 refers to the calculation result obtained by the above step 1305, temporarily stored in the memory 103 for example, identifies a combination of the inspection cycle and the water distribution pipeline replacement timing that minimizes total LCC, and displays the combination on the output device 106 as the optimal water distribution pipeline replacement timing and optimal inspection cycle (step 1306).

[0096]

As described above, when the calculation of the optimal replacement timing is completed for a target water distribution pipeline, the optimal replacement timing calculation unit 114 of the pipeline replacement planning support system 100 increments the value "N" set in the memory 103 in step 701 by 1 (step 708), and the process returns to step 702. In the series of processings from step 702 to step 708, various costs, a water leakage inspection cycle and a

water distribution pipe replacement timing are calculated for a certain water distribution pipeline.

[0097]

The pipeline replacement planning support system 100 repeats step 702 to step 708 above until the calculation of the optimal replacement timing and the optimal inspection timing is completed for all the water distribution pipelines. When the calculation of the optimal replacement timing and the optimal inspection timing is completed for all the water distribution pipelines (step 702: Y), the pipeline replacement planning support system 100 stores the values for the optimal replacement intervals and the optimal inspection intervals for the respective water distribution pipelines in the corresponding records in the cost calculation information database 125, displays the result values on the output device 106 (step 1307), and ends the process.

[0098]

Third Embodiment

Next, a third embodiment of the present invention will be described with reference to Figs. 15-18.

In the third embodiment, processing in which designated conditions are considered in calculations performed by the pipeline replacement planning support system 100 will be described.

[0099]

Here, graph 1500 in Fig. 15 indicates the number of replaced pipelines each year from the first year to the 20th year when the water distribution pipelines are replaced based on the water distribution pipeline replacement timing calculated as described above in the first embodiment. Graph 1501 indicates a replacement cost each year from the first year to the 20th year, again when the water distribution pipelines are replaced based on the water distribution pipeline replacement timing calculated as described above in

the first embodiment. It is to be noted that the values shown in the graphs 1500, 1501 are the pipelines targeted for replacement and the replacement costs calculated by the pipeline replacement planning support system 100 as shown in Fig. 17.

[0100]

As is apparent from the graphs 1500, 1501, the number of pipelines replaced changes year by year, and accordingly the replacement cost fluctuates significantly year by year. On the other hand, for entities that maintain and operate water distribution pipelines, an annual budget is assigned for replacement of the water distribution pipelines. Therefore, it is preferable for those entities that drastic changes in the replacement cost are minimized.

[0101]

Accordingly, in the pipeline replacement planning support system 100 of the third embodiment, a process of calculating the water distribution pipeline replacement timing that minimizes annual water distribution pipe LCC for each pipeline where an upper limit is set on the replacement cost of the water distribution pipelines for each year is described. It is assumed that the pipeline replacement planning support system 100 solves the optimization problem below and calculates an updated replacement timing for each water distribution pipeline. Needless to say, the pipeline replacement planning support system 100 of the second embodiment has pre-stored programs with algorithms (which may be known algorithms) for solving the above optimization problem in the storage device 101 and the functional units of the pipeline replacement planning support system 100 of the second embodiment are able to utilize these programs as required.

[0102]

The formula specifically utilized in the pipeline

replacement planning support system 100 of the third embodiment is as follows:

[0103]

$$\underset{t_i}{MIN} \; LCC_total \quad \text{s.t.} \quad IC_\max \le IC_0 \qquad \cdots\cdots\cdots \text{Formula 20}$$

$$IC(T) = \sum_{i \in A} IC_i \qquad A = \{i \mid t_i = T\} \qquad \cdots\cdots \text{Formula 21}$$

$$IC_\max = MAX\{IC(1), IC(2), \ldots\ldots, IC(T)\} \qquad \cdots\cdots\cdots \text{Formula 22}$$

$$LCC_total = \sum_{i=1}^{n} LCC_i(t_i) \qquad \cdots\cdots \text{Formula 23}$$

[0104]

In the formulas, Formula 20 is the one that expresses the optimization problem. Formula 20 means the optimization problem for obtaining t_i minimizing LCC_total.

[0105]

In this formula, LCC_total is the sum of the annual water distribution pipe LCC of the all water distribution pipelines as a target of replacement and is calculated using Formula 23. In Formula 23, a water distribution pipe LCC_i is a water distribution pipe LCC for a water distribution pipe i and is expressed as a function of a replacement cycle t_i. The function , water distribution pipe LCC_i can be obtained by substituting t_i for n in Formula 14.

[0106]

IC_max in Formula 20 is a maximum value of the replacement cost and given by Formula 22. MAX is a function for obtaining a maximum value of the variable in {}. IC_0 is an upper limit on the replacement cost and may be designated manually. It is to be noted that IC(T) in Formula 22 is the replacement cost in the Tth year and is calculated by Formula 21. IC_i is the replacement cost of the water distribution pipeline i.

[0107]

The pipeline replacement planning support system 100 calculates the replacement cost of each water distribution pipeline to be replaced illustrated in Fig. 16 and further calculates the values for the replacement target pipelines and the replacement cost each year shown in Fig. 18 by solving the maximization problem of the above Formula 20. In this case, although the total LCC slightly increases compared to using the optimal water distribution pipeline replacement timing of the first embodiment, the replacement cost can be evened out since the water distribution pipeline replacement timing is calculated with an upper limit on the replacement cost each year. The graphs 1510, 1511 in Fig. 15 show an example in which the calculation result obtained by solving the optimization problem of Formula 20 with the pipeline replacement planning support system 100 is shown graphically and displayed on the output device 106. As apparent from the graphs 1510, 1511, since an upper limit of 80 million Japanese yen is provided each year, the replacement cost is evened out.

[0108]

It is to be noted that, as shown by graph 1900 in Fig. 19, for a given water distribution pipeline, a replacement timing may be calculated using a manually designated annual water distribution pipe LCC 1402 instead of the annual water distribution pipe LCC 1401 calculated with Formula 14. Accordingly, such a pipeline replacement plan may be made that the pipes are replaced earlier or later by a predetermined period than an optimal replacement timing obtained by each embodiment above. This flexibility makes it possible to prepare pipeline replacement plans that take into consideration various circumstances, for example, such that replacement of important water distribution pipelines should be undertaken earlier than as calculated with allowance for cost overruns within a certain range.

[0109]

Hereinbelow, an actual pipeline replacement planning support method according to the third embodiment will be described referring to the drawings.

Fig. 20 is an example of the pipeline replacement planning support method according to the third embodiment. In this case, the pipeline replacement planning support system 100 accepts designation through the input device 105 (step 1601) of an age of replacement target, an upper limit on the replacement cost IC_0, and a formula for the annual water distribution pipe LCC shown in Fig. 19 as the line 1402. Here, the age is 20 years, for example in Fig. 15.

[0110]

Subsequently, the pipeline replacement planning support system 100 solves the optimization problem of Formula 20 above under the condition of the user designation received at step 1601 and calculates an optimal replacement timing for each water distribution pipeline (step 1602). Further, the pipeline replacement planning support system 100 stores the optimal replacement timing in the calculation result at step 1602 in the record of the corresponding water distribution pipeline in the cost calculation information database 125, draws the graphs for the number of pipelines and the replacement cost of each replacement year, respectively, according to the calculation result, and displays the graphs on the output device 106 (step 1603). The graphs drawn above are the same as the graphs 1510, 1511 in Fig. 15.

[0111]

Hereinabove, the best mode for carrying out the present invention and the like are specifically described. However, the present invention should not be construed as limitative thereto, and may be modified in many ways within the gist thereof.

[0112]

According to the present embodiments, assistance of planning an optimal pipeline replacement plan for minimizing a life-cycle cost of a pipeline is made possible.

[0113]

According to the description of the present application, at least the followings are made clear: First, in the pipeline replacement planning support system of the present embodiments, the processor may be configured to calculate loss caused by water leakage based on a water leakage inspection cycle performed at predetermined time intervals and the cost calculation information, and calculate the maintenance cost based on the calculated loss in calculation of the maintenance cost.

[0114]

According to the above, it is made possible that the water distribution pipeline replacement timing for minimizing a life-cycle cost of each water distribution pipeline taking water leakage from a water distribution pipe that is simply maintained without repair into consideration is precisely determined and presented to a user. Therefore, assistance of planning a pipeline replacement plan that has effectively reduced a life-cycle cost of water distribution pipes is made possible.

[0115]

Further, in the pipeline replacement planning support system of the present embodiments, the processor may be configured to calculate maintenance cost of service pipes caused by water leakage of the service pipes based on the cost calculation information, calculate a total life-cycle cost of the water distribution pipes and the service pipes using the maintenance cost of the service pipes and the life-cycle cost of the water distribution pipes, and determine a replacement timing of the water distribution pipes and a time interval between inspections for leakage that minimizes the calculated

total life-cycle cost.

[0116]

According to the above, it is made possible to present to a user the water distribution pipeline replacement timing and the water leakage inspection cycle for minimizing the total cost taking into consideration both the water distribution pipe life-cycle cost and the service pipe maintenance/management cost as the service pipe life-cycle cost. Therefore, assistance of planning a pipeline replacement plan that has effectively reduced a life-cycle cost of water distribution pipes is made possible.

[0117]

Moreover, in the pipeline replacement planning support system of the present embodiments, the processor may be configured to calculate the replacement timing of the water distribution pipes that provides the replacement introduction cost in each fiscal year for a predetermined future time period fulfilling predetermined conditions and minimizes a total life-cycle cost of all of the water distribution pipes to be replaced in the predetermined future time period in calculating the optimal replacement timing of the water distribution pipes.

[0118]

According to the above, it is made possible to determine a water distribution pipeline replacement timing under predetermined conditions of a pipeline replacement cost each year and present the determined timing to the user. Therefore, assistance of planning a pipeline replacement plan that satisfies the budget condition each year corresponding to the pipeline replacement cost is made possible.

[0119]

Further, in the pipeline replacement planning support system of the present embodiments, the processor may be configured to accept a designated life-cycle cost of a water

distribution pipe designated, and calculate a timing of replacing the water distribution pipes that minimizes the total of the life-cycle costs including the designated life-cycle cost in calculating the optimal replacement timing of the water distribution pipes.

[0120]

According to the above, it is made possible to establish a pipeline replacement plan in which, taking into consideration various circumstances, a certain pipeline should be replaced earlier than the timing according to an ordinary calculation result by the pipeline replacement planning support system due to its importance, and/or that a certain pipeline should be replaced later than the timing according to an ordinary calculation result by the pipeline replacement planning support system due to its relatively lower importance than the others.

DESCRIPTION OF REFERENCE SYMBOLS

100 Pipeline replacement planning support system

101 Storage device

102 Program

103 Memory

104 Processor

105 Input device

106 Output device

111 Water distribution pipe introduction cost calculation unit

112 Water distribution pipe maintenance/management cost calculation unit

113 Water distribution pipe LCC calculation unit

114 Optimal replacement timing calculation unit

115 Water leakage loss cost calculation unit

116 Service pipe maintenance/management cost calculation unit

117 Total pipeline LCC calculation unit

118 Optimal replacement timing/optimal inspection cycle calculation unit

125 Cost calculation information database

What is claimed is:

1. A support system for designing a pipeline replacement plan, comprising:

a storage device configured to store cost calculation information including pipe attribute information; and

a processor configured to:

calculate replacement introduction cost required for replacing water distribution pipes and maintenance cost of water distribution pipes caused by water leakage in the water distribution pipes based on information for cost calculation:;

calculate a life-cycle cost of the water distribution pipes using the calculated replacement introduction cost and maintenance cost;

calculate an optimal replacement timing of the water distribution pipes that minimizes the calculated life-cycle cost; and

display, on an output device, the calculated replacement introduction cost, maintenance cost, life-cycle cost, and the optimal replacement timing for the water distribution pipes.

2. The support system for designing a pipeline replacement plan according to claim 1, the processor further configured to calculate loss caused by water leakage based on a water leakage inspection cycle performed at predetermined time intervals and the cost calculation information, and calculate the maintenance cost based on the calculated loss in calculation of the maintenance cost.

3. The support system for designing a pipeline replacement plan according to claim 2, the processor further configured to calculate maintenance cost of service pipes caused by water leakage of the service pipes based on the cost calculation information, calculate a total life-cycle cost of

the water distribution pipes and the service pipes using the maintenance cost of the service pipes and the life-cycle cost of the water distribution pipes, and determine a replacement timing of the water distribution pipes and a time interval between inspections for leakage that minimizes the calculated total life-cycle cost.

4. The support system for designing a pipeline replacement plan according to claim 1, the processor further configured to calculate the replacement timing of the water distribution pipes that provides the replacement introduction cost in each fiscal year for a predetermined future time period fulfilling predetermined conditions and minimizes a total life-cycle cost of all of the water distribution pipes to be replaced in the predetermined future time period in calculating the optimal replacement timing of the water distribution pipes.

5. The support system for designing a pipeline replacement plan according to claim 4, the processor further configured to accept a designated life-cycle cost of a water distribution pipe designated, and calculate a timing of replacing the water distribution pipes that minimizes the total of the life-cycle costs including the designated life-cycle cost in calculating the optimal replacement timing of the water distribution pipes.

6. A method of supporting design of a pipeline replacement plan implemented by a computer including a storage device configured to store cost calculation information including pipe attribute information and a processor, comprising:

calculating replacement introduction cost required for replacing water distribution pipes and maintenance cost of

water distribution pipes caused by water leakage in the water distribution pipes based on information for cost calculation;

calculating a life-cycle cost of the water distribution pipes using the calculated replacement introduction cost and maintenance cost;

calculating an optimal replacement timing of the water distribution pipes that minimizes the calculated life-cycle cost; and

displaying, on an output device, the calculated replacement introduction cost, maintenance cost, life-cycle cost, and the optimal replacement timing for the water distribution pipes.