Study Committee C1

Power System Development and Economics

Paper 10597_2022

Development of asset management method for power distribution equipment

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Motivation

- In Japan, during the period of high economic growth from the 1950s to 1970s, a large amount of power distribution assets were installed and are about to be replaced.
- To ensure resilience and safety network, maximizing investment benefits under the limited resources such as investment costs and labor force are necessary.

Method/Approach

OVERVIEW

- Our method is called Value-Based Asset management, which evaluates the Value for asset replacement cost and draws up an investment plan to maximize Value.
- The two key index of our method are:-
  1. An evaluation of Asset Risk
  2. An evaluation of Value

EVALUATION OF ASSET RISK

The Asset Risk is evaluated by multiplying the probability of asset failure（PoF）by the consequence of failure(CoF).

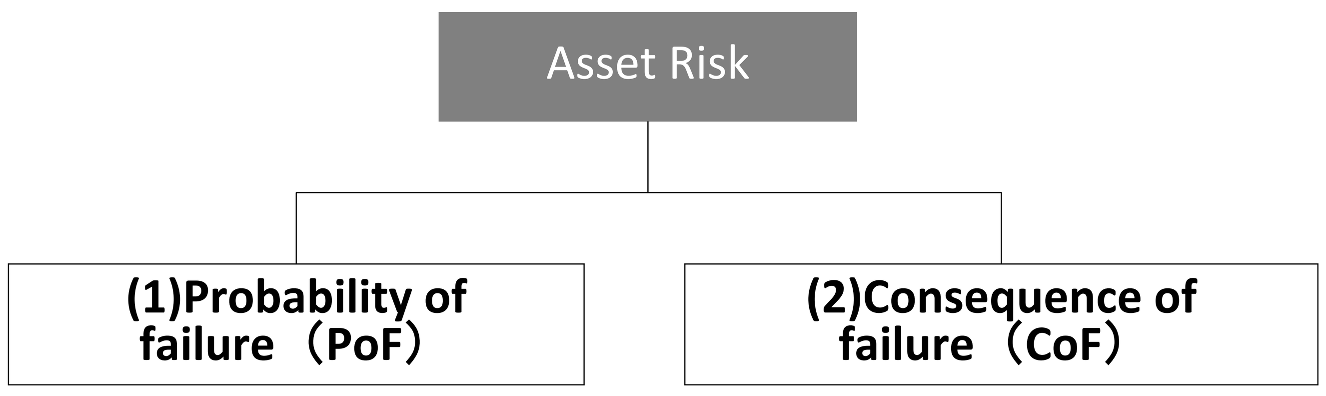

Fig 1: Asset Risk

(1)Probability of failure(PoF)

- Probability of failure(PoF) represents the likelihood of a Condition-based Functional Failure occurring, and we evaluate this for the approximately 26 million distribution assets such as electric poles, power lines, and transformers.
- PoF is derived by the failure probability curve, which is created by three steps followings.

  I. Create the Survivorship curve *f* (t) for each asset type based on age, using the inspection results and the asset failure records.

  II. Create the Failure rate curve *P* (t) with 1-*f* (t), using *f* (t)

  III. Create the Failure probability curve *F* (t) by approximating *P* (t) created in Step Ⅱ to the Weibull distribution.

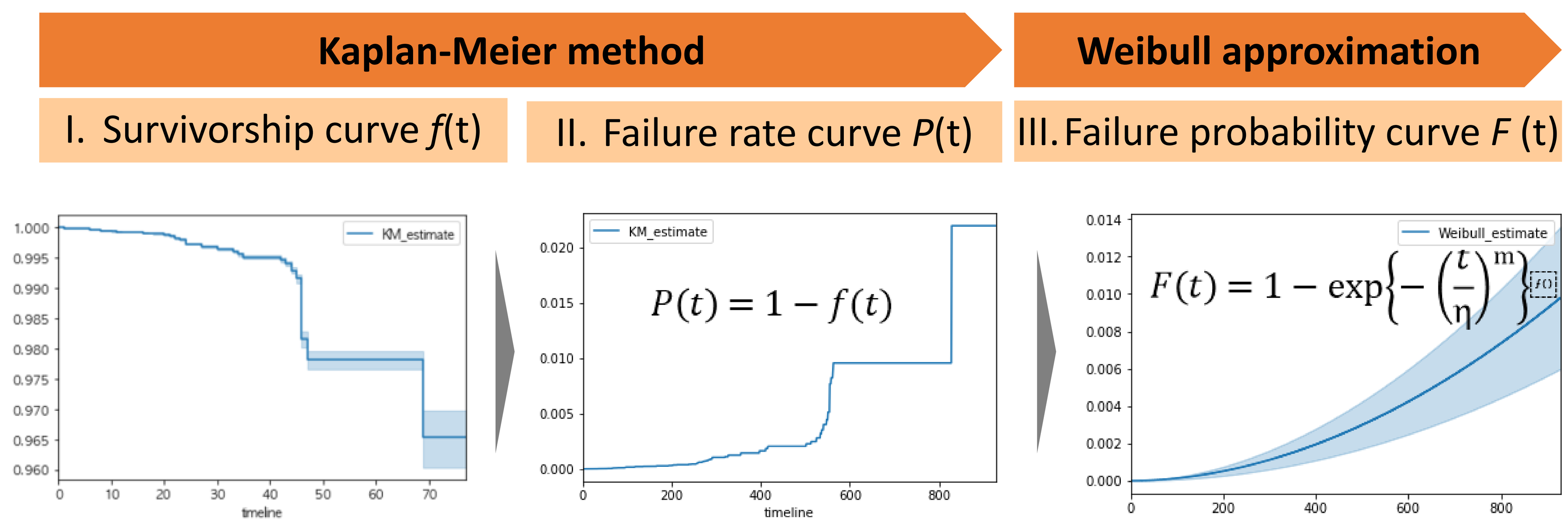

Fig 2: Statistical processing for calculations of probability of failure

(2) Consequence of Failure(CoF)

- Consequence of Failure(CoF) is the impact resulting from asset failure and is evaluated for individual assets using three specified categories below.

  i. Consequence of power supply reliability

  ii. Consequence of safety for residents

  iii. Consequence of business operations

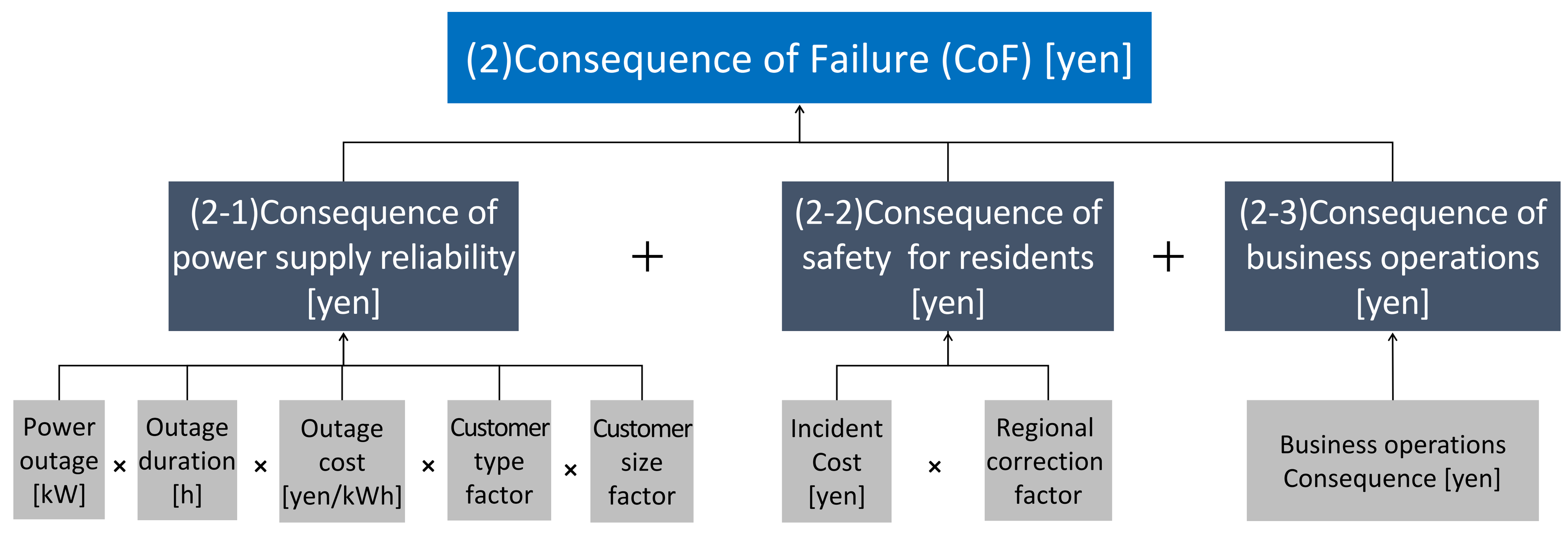

Fig 3: Consequence of failure

(2-1)Consequence of power supply reliability

- Consequence of power supply reliability is calculated by multiplying the power outage (kW) caused by asset failure, the outage duration (hour), and the outage cost (yen/kWh).
- The power outage (kW) is the sum of contracted kW of all customers in the section of switches that includes the failed asset.

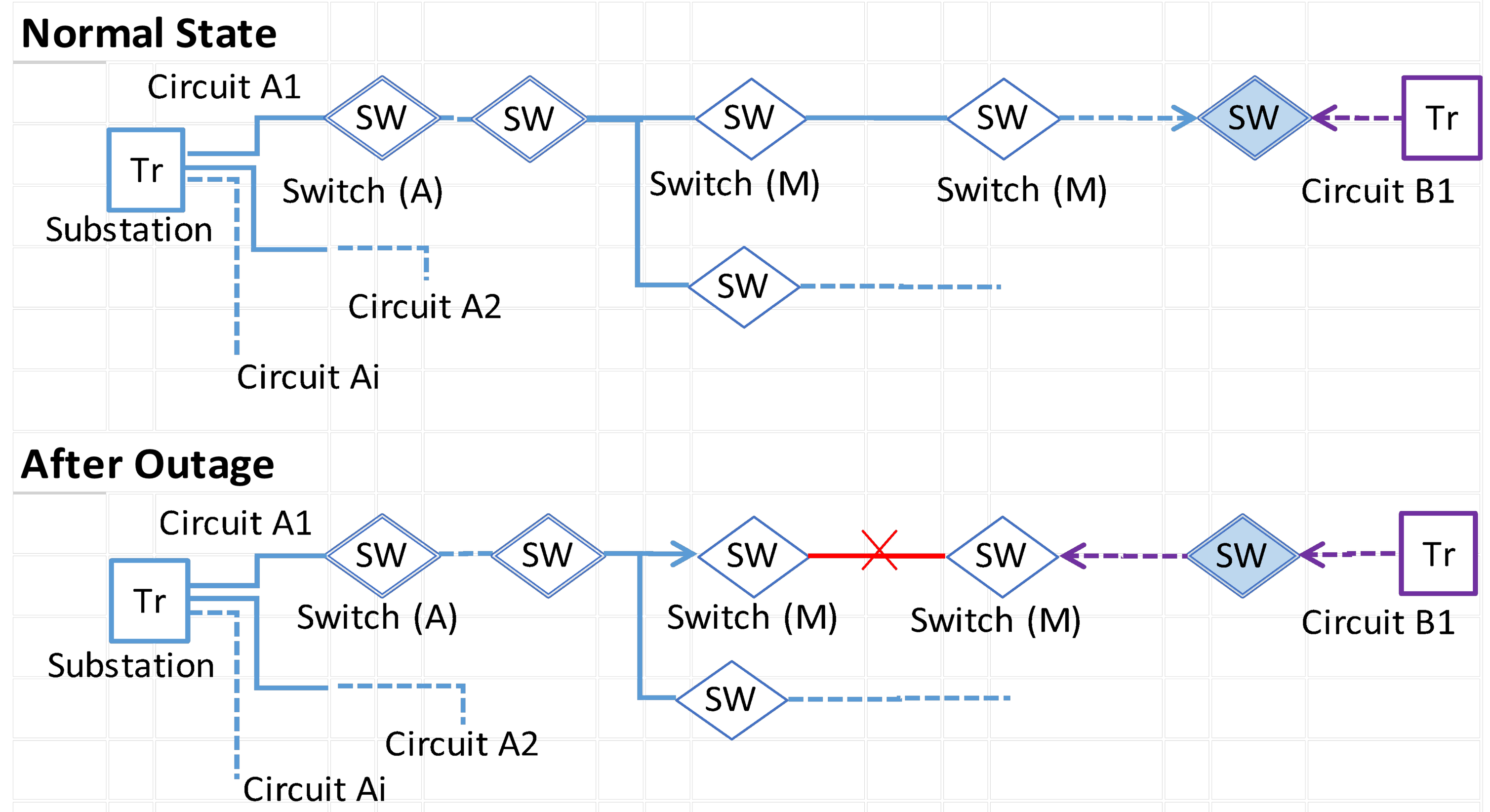

Fig 4: Distribution Network Configuration in Japan (typical)

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- The outage duration is set based on our records.
- The cost of power outages (in yen/kWh) is calculated by dividing the total GDP and annual electricity consumption in the region.

Table 1(a): Consequence of power supply reliability

Outage duration [h]		Outage cost [yen/kWh]	
Overhead	2	All	675
Underground	12		

- Consequence of power supply reliability is weighted by the type and number of customers included in the outage section. Specifically, a factor of 1.1 ~ 2.0 is set for customer types with high social impact, such as hospitals, government agencies like police and fire departments, and consumers with life-supporting ventilators.

Table 1(b): Consequence of power supply reliability

Customer type factor		Customer size factor	
Critical	1.1-2.0	over 500	4.0
		2-499	1-4
Typical	1.0	0-1	1.0

(2-2)Consequence of safety for residents

- Consequence of the safety for residents represents the impact of death or serious injury due to asset failure multiplied by Incidents consequence and Regional Correction Factor.
- Incidents consequence is equivalent to compensation costs for "death or serious injury" to the public caused by an accident like a power distribution line falling due to asset failure.
- The regional correction factor is weighted by considering each asset site's population density.

Table 2: Consequence of safety for residents

Incident consequence [×10^6 yen]		Regional correction factor	
Death	240	Per region	1.00-0.47
Injury	39.6-4.08		
None	0		

(2-3)Consequence of business operations

- Consequence of business operations is equivalent to the required labor cost to conduct emergency equipment inspection in the event of an asset failure. We record past emergency inspections of assets installed in areas associated with railways, rivers, and arterial roads.

Table 3: Consequence of business operations

Association	Consequence [×10^6 yen]
Railways / Rivers / Arterial roads	4.0

Evaluation of Value

- The asset replacement plan is decided so that the objective function shown in eq. 1 becomes maximum.
- The first term of eq. 1 is the present Value of the reduction in the asset risk due to asset replacement.
- The second term of eq. 1 is the present Value of the asset replacement.
- In summary, the Value obtained from the asset replacement is calculated as the difference between the reduction in the asset risk via asset replacement cost.

$$v(i) = \sum_{m=1}^{m} \left[\sum_{t=i}^{n} \left\{ \frac{\left(R_{\alpha(m,i,t)} - R_{\beta(m,i,t)}\right)}{(1+Pr)^t} \right\} - \frac{C_{(m)}}{(1+Pr)^i} \right] \quad \cdots \text{eq.1}$$

Constraints: for every i

$$K_{C(i)} \geq \sum_{n=1}^{n} \left\{ \sum_{k=1}^{k} \left(C_{(n,k)} \times V_{(i,n,k)} \right) \right\} \quad \cdots \text{eq.2}$$

$$K_{N(i)} \geq \sum_{n=1}^{n} \left\{ \sum_{k=1}^{k} \left(N_{N(n,k)} \times V_{(i,n,k)} \right) \right\} \quad \cdots \text{eq.3}$$

for every equipment type N

$$K_{L(i)} \geq \sum_{n=1}^{n} \left\{ \sum_{k=1}^{k} \left(L_{(n,k)} \times V_{(i,n,k)} \right) \right\} \quad \cdots \text{eq.4}$$

eq. 2

- The investment cost in each fiscal year shall be a Value obtained by multiplying the unit cost of the replacement work (work unit) and the replacement work volume for each workplace and asset type.

eq. 3

- The volume of materials in each fiscal year shall be a Value obtained by multiplying the volume of materials required per work unit and the replacement work volume for each workplace and asset type.

eq. 4

- The total labor force in each fiscal year shall be a Value obtained by multiplying the labor force required per work unit and the replacement work volume for each workplace and asset type.

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Results

- Fig 5 (a) shows the asset replacement plan using the conventional based on the expected life of the assets. With the conventional method, there is a significant variation in the annual asset replacement volume.
- Fig 5 (b) shows the asset replacement plan using the method proposed in this paper. Prioritization of replacements by Value, considering investment costs, labor force, and material volume constraints for each year, has resulted in a more level annual replacement volume.

Fig 5 (a): Conventional method (Time Based Management)

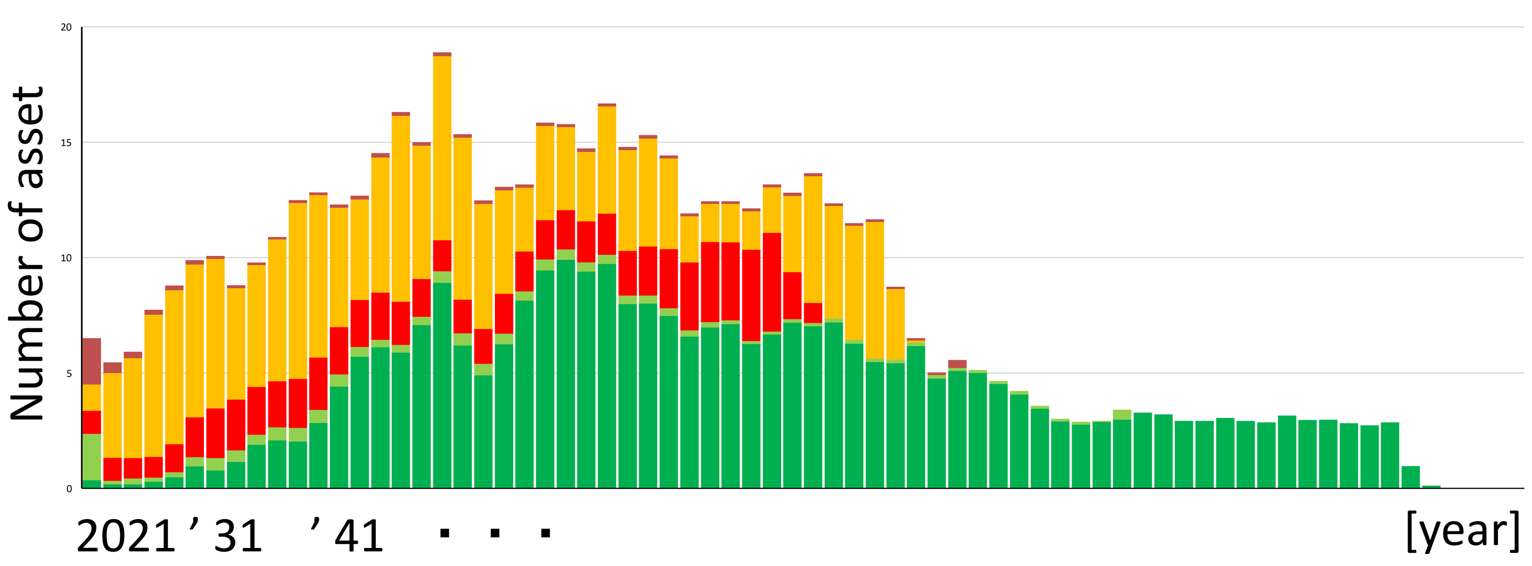
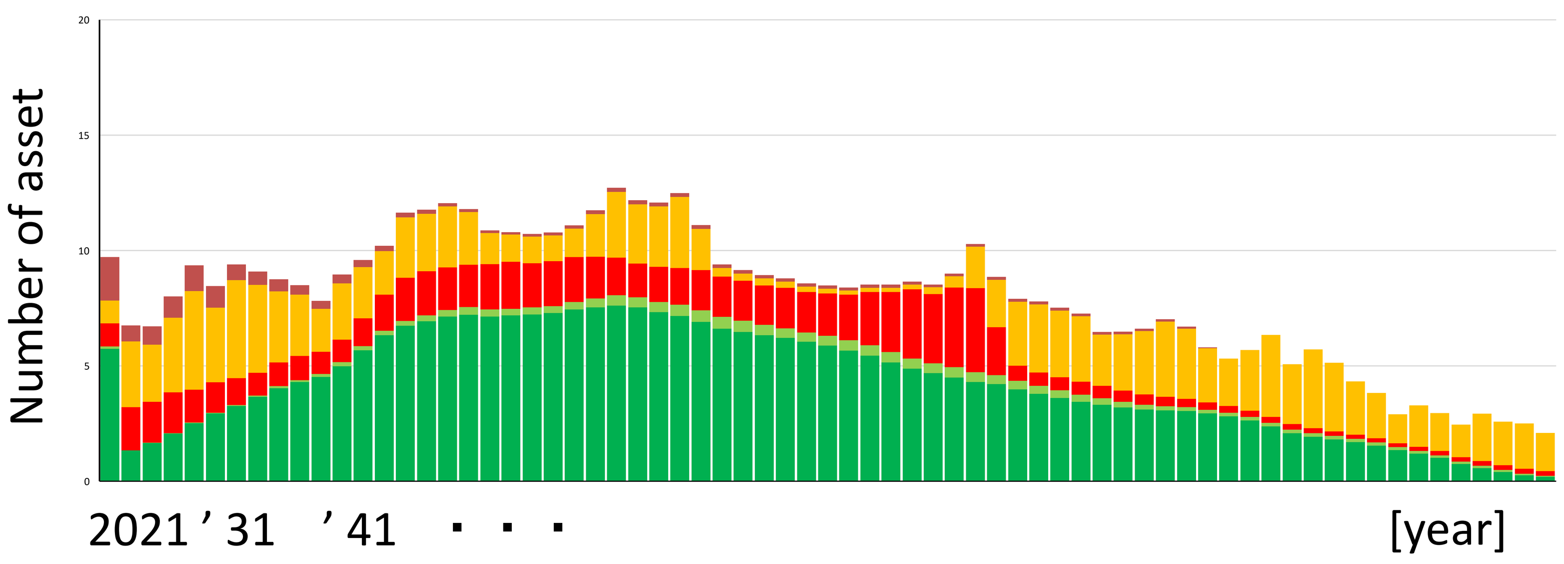


Fig 5 (b): Proposed method (Value Based Management)



- Next, a 10 year asset replacement plan was formulated with investment cost as a constraint. Fig 6 shows the labor force required for the asset replacement plan.
- The required labor force for Concrete Poles has decreased compared with the conventional method. On the other hand, in the case of Copper Power lines Type A, the required labor force using the proposed method has increased because the Value (eq. 1) obtained by the replacement of asset Copper Power lines Type A is higher than that of Concrete Poles.

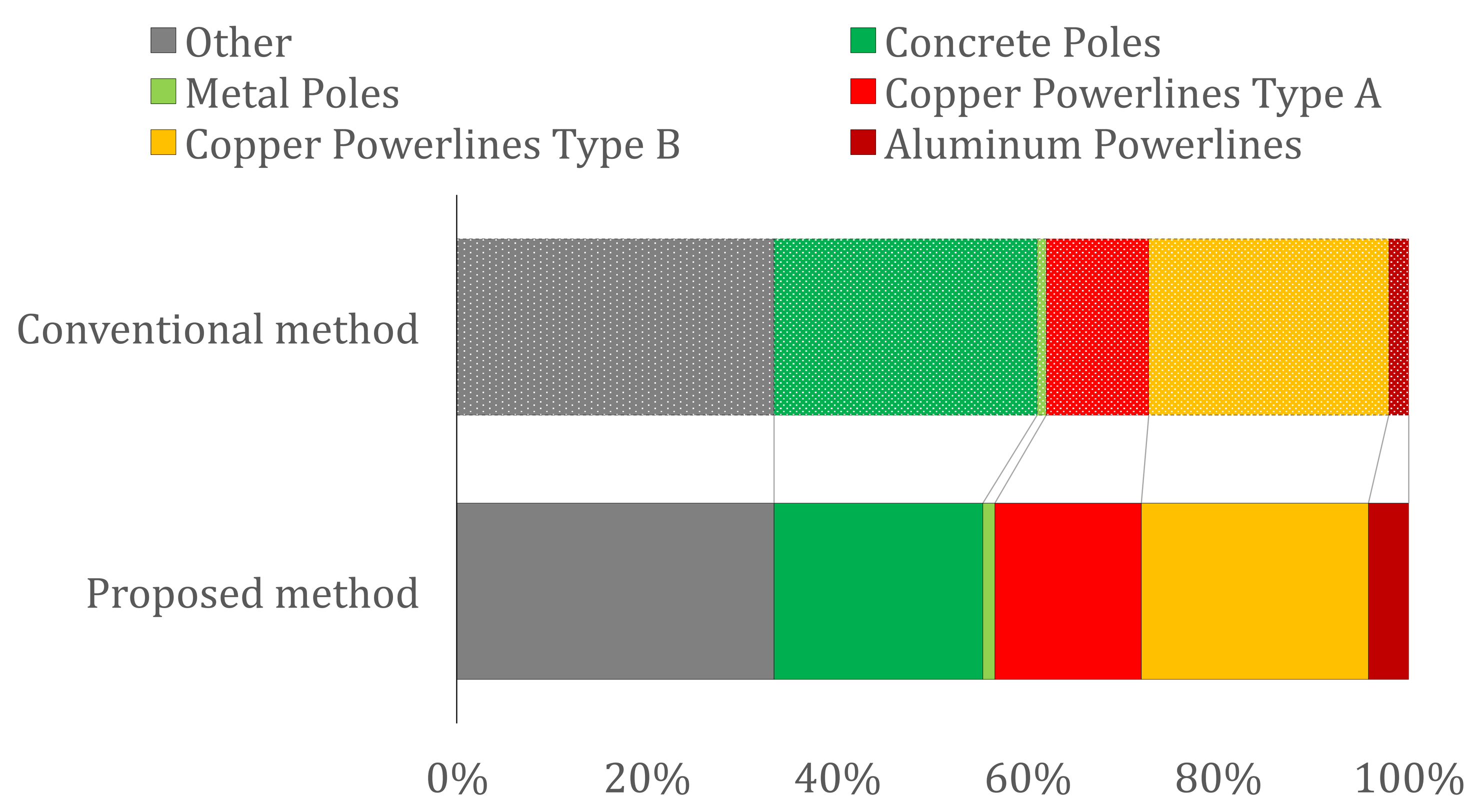


Fig 6: Comparison of required labor force

Discussion

- By optimizing the asset replacement plan using the proposed method, the maximum Value achieved from target functions and constraints in eq.1-4 resulted in 22% improvement compared to the previous planning method.

Table 4: Comparison of Value of Asset replacements

Total for years 2021 ~ 2030	Conventional method	Proposed method (compared to conventional methods)
$\frac{Achieved\ Value_{[yen]}}{Investment\ Cost_{[yen]}}$	2.935	3.581 (+ 22.0%)

Conclusion

- In this paper, we have proposed a method to quantify the asset risk of power distribution equipment and to formulate an asset replacement plan whose Value is maximized by calculating the difference between the reduction in asset risk via replacement and the intervention cost required for replacement.
- It was confirmed through simulation that the proposed method reduces the annual fluctuation of replacements while achieving a higher Value than the conventional method.
- In the future, We will refine the probability of failure by accumulating the surveillance and inspection results and the failure records of assets.