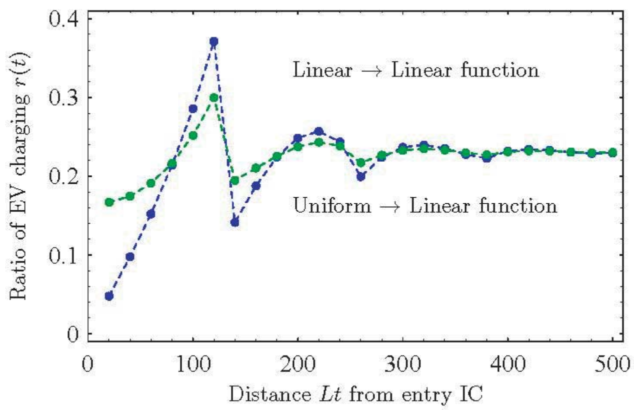

Fig. 6. $r(t)$ according to different initial power-feed patterns $q(t)$.

further away from the entry IC. By using the following limit theorem for the z transform,

$$\frac{1-z}{z}F(z) = \lim_{t\to\infty} f(t), \tag{18}$$

a convergence value for $r(t)$ for both linear and uniform functions can be calculated as

$$\lim_{t\to\infty} r_L(t) = \frac{3}{2T+1}, \tag{19}$$

$$\lim_{t\to\infty} r_U(t) = \frac{2}{T+1}. \tag{20}$$

Next, we examined the impact of intervals between power-feed facilities. Comparisons when $L = 60$ and $T = 2$ are shown in Fig. 5. A linear function was assumed for the power-feed patterns, and the charging facilities in this case were only installed at SAs located at approximately 60 km intervals. As is clear from this figure, the number of power-feed facilities is reduced to one-third, and the ratio of EVs charging at each facility increases. Moreover, as a result of the limited number of power-feed facilities, it can be confirmed that variation at each facility does not become uniform even if the distance from the entry IC is longer.

3.5 Considerations for initial power-feed pattern

As the last point regarding formulation, we discuss the generalization applied to EVs that are "not" charged immediately before entering the highway. The generalization can be applied easily to this assumption by adding

$$q(t) \overset{\text{def.}}{=} [\text{probability of recharging at the } t+1\text{th facility from the entry IC}] \tag{21}$$

and $p(t)$. In this case, the following recurrence equation is formed from $r(t)$, $p(t)$, and $q(t)$:

$$\begin{cases} r(0) = 1 \\ r(t+1) = q(t) - p(t) + \displaystyle\sum_{\tau=0}^{t} r(\tau)\cdot p(t-\tau). \end{cases} \tag{22}$$

Therefore, from

$$z^{-1}\{R(z) - r(0)\} = Q(z) - P(z) + R(z)P(z), \tag{23}$$

Fig. 7. Target highway network.

$r(t)$ can be derived from

$$r(t) = Z^{-1}\left[\frac{zQ(z) - P(z) + 1}{1 - zP(z)}\right], \tag{24}$$

and by using inverse z transform of $R(z)$. The result to consider initial power-feed pattern $q(t)$ is shown in Fig. 6. Assuming $q(t)$ = Uniform function, there are a large number of EVs that are not fully charged when entering the IC. We see that the ratio of EVs charging at facilities 1–3 increases. On the other hand, the ratio of EVs charging at facilities 4–6 decreases. As a result, the initial rise in the first charging peak (or "power-feed peak") is not as severe. Because the first recharge (or "initial power-feed") takes place by the sixth facility, from the seventh facility onward, there is no significant change. Eventually, we see that the numbers converge to similar values. The results show that the consideration of initial charge patterns (or "initial power-feed pattern") largely influences $r(t)$ through the initial charging peak (or "initial power-feed peak").

4. Application to the Japanese Highway Network

In this section, we conduct a calculation for the Japanese Highway Network using the model described in Section 3.

4.1 Target network and preparation of OD data

In this section, the model is applied to a Japanese highway network for examining the need for infrastructure development with the popularization of EVs. The target network is described in Fig. 7, which consists of 1,030 ICs (nodes). There are also 112 SAs and 260 PAs, which are potential locations of EV charging facilities. We incorporated all Japanese highways besides those in Hokkaido and