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FLEXIBILIZATION IN TARIFFING FOR PASSAGES BY POLISH PUBLIC TRANSPORT VIA PREPAID SERVICES AND GPS NAVIGATION WITH CONTROLLERS OF TIME AND DISTANCE

A conception of tariffing passages flexibly by simultaneously facilitating easier controls of paying fares is suggested. Formulae of charging fares, which regard the factual passage by its elapsed time and passed distance, are stated. A scheme of executing fare payments and their control with using GPS navigators and controllers of time and distance is given.

Keywords: tariffing passages, charging fares, paying fares, prepaid services.

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ГНУЧКА ТАРИФІКАЦІЯ ПАСАЖИРСЬКИХ ПЕРЕВЕЗЕНЬ ПОЛЬСЬКИМ ГРОМАДСЬКИМ ТРАНСПОРТОМ НА ОСНОВІ ПОПЕРЕДНЬО ОПЛАЧЕНИХ ПОСЛУГ І GPS-НАВІГАЦІЇ З КОНТРОЛЕРАМИ ЧАСУ ТА ВІДСТАНІ

Представляється концепція гнучкої тарифікації пасажирських перевезень за одночасного сприяння полегшеному контролюванню сплати за проїзд. Викладено формули для нарахування сплат, котрі відносяться до фактичного перевезення за відповідним часом, що сплинув, і пройденою відстанню. Подається схема виконання сплат за проїзд та їх контроль з використанням GPS-навігаторів і контролерів часу і відстані.

Ключові слова: тарифікація перевезень, нарахування сплат, виконання сплат, попередньо оплачені послуги.

Introduction

Public transport is an essential part of a modern city/town infrastructure. The larger city's area, the higher importance of transport emerges. Its complexity increases as well by a roughly exponential law [1, 2].

A public transport system is generally of seven components (see their interrelationship in Figure 1):

1) a transport park (autobuses, trolleybuses, tramways, etc.);
2) a driving staff (operators on tramways and subways);
3) a management system (including software for office and supporting departments);
4) software and hardware on transport units and at principal stops/stations;
5) a system of tariffs;
6) a personnel of fare payment controllers;
7) a communication network (roads for autobuses and trolleybuses, railways for tramways and subways).

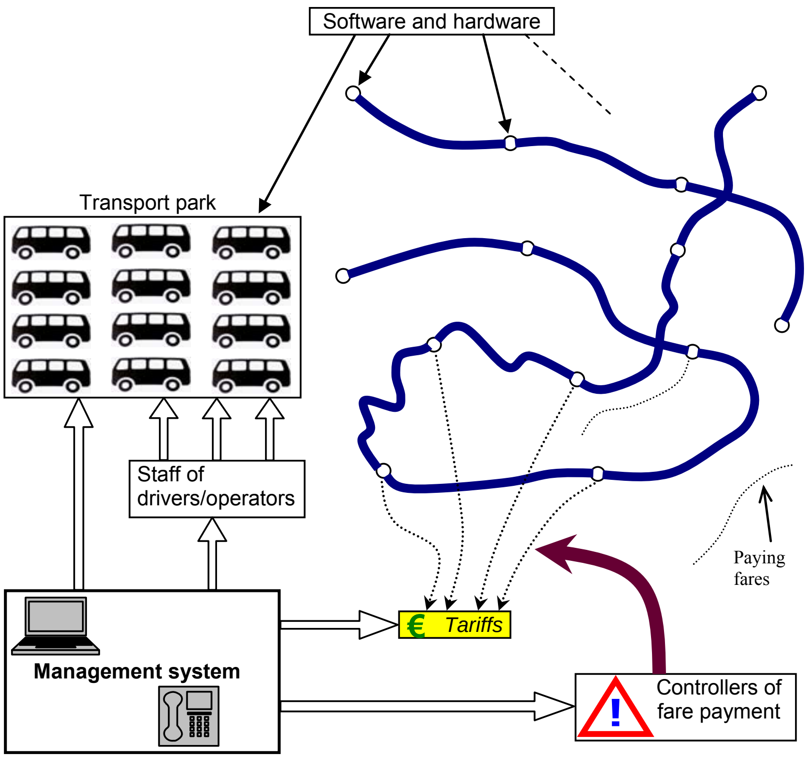

Figure 1. Main components of a public transport system and their simplified interrelationship

Despite a common opinion about that the single purpose of public transport system is „to transport people", public transport is conceived for fulfilling a few tasks [1, 3, 4]:

1) accomplishing passages (the primary task followed by those ones below to make that accomplishment as best as possible);

2) safe passages (security is not implied here as it is not an obligation of a transport company, although this is a communication type and one of basic principles of, for instance, telecommunication/data-transfer is security; an exception is broadcast and telecast);

3) passages should be fast (which is in some opposition to safety);

4) physical comfort (comfortable seats, handrails and handholds, seats for passengers with disabilities, for little children and aged people);

5) psychological comfort (appropriate stops, non-overcrowded compartments, intelligible fares, punctual timing and information about schedule).

While public transport system is not complicated (for small towns), nowadays it is not a problem to keep developing further each of those components. Because of transport system complications, big cities have major tasks on the components, especially on that concerns software, transport hardware, and, curiously enough, tariffs. The last just seems so unconcerned or „additional", not influencing much on the whole public transport system. As a matter of fact, the system of tariffs has its own dramatic impact on the public transport development, although it is revealed subsequently, as an aftermath [5, 6].

Basic demerits of tariffing (obviously, relating not only to Poland or to European Union) are the following:

1) some tariffs have considerable gaps in fares (for instance, 3.20 zł on common line and 4.20 zł on fast line in Gdynia, although difference in speeds is not apparent, and stops are mostly the same), which may be perceived as a kind of demotivation;

2) it is very difficult for a passenger, for whom the public transport is a something new (say, who has never been to Poland before or never used such a communication network previously), to remember all the aspects of buying/paying fares, differences between interval-valid passages (for example, 24-hour and 72-hour fares), validity of passages over different fare routes (like in transport communication among Gdansk, Sopot, Gdynia), etc., that may lead the passenger to getting fined (that is unfair because the passenger's delinquent action/behavior is not intentional);

3) a great diversity of tariffs may confuse fare payment controllers themselves (rarely, though);

4) if drivers on a route are allowed to sell tickets, a great diversity of tariffs may confuse also them, that is far more dangerous [7, 8] because it is an additional distraction (obviously, while the vehicle is moving; but even if tickets are sold during the stopping, those few minutes are to be compensated by a higher speed to the next stop — remember the public transport task #5).

Apparently, those demerits are removable if fares become not so rough along with that a greater diversity of tariffs becomes easier to familiarize oneself with it. This is possible by introducing a system of payments resembling prepaid services in mobile/cellular communication, which is believed to make tariffs more flexible [5, 6, 9, 10]. Such fare flexibility, except a few obvious benefits, will allow passengers to feel independent of not knowing specific rules of a public transport system.

Goal and tasks to be fulfilled

Goal of the article. Issued from lacks of perfection in public transport system tariffication, the goal of the present article is to suggest a conception of tariffing passages flexibly by simultaneously facilitating easier controls of paying fares. By that, the personnel of fare payment controllers remains the same, but its tasks in controlling fare payments shall be easier. This is going to be settled via prepaid services and GPS navigation with controllers of the elapsed time and passed distance.

Tasks to be fulfilled for achieving the article's goal. For achieving the article's goal, the following three tasks are to be fulfilled:

1) to state formulae of charging fares, which could regard the factual passage by its elapsed time and passed distance;

2) to suggest a scheme of executing fare payments and their control;

3) to make a conclusion on an outlook for implementation of the suggested scheme and its components.

A method of charging flexible fares

Variables in calculating tariffs. First of all, we should list factors that directly influence on charging fares. Mathematically, these factors can be interpreted as variables.

Consider two neighboring stops (Figure 2) belonging to a route, where a passenger is, for disambiguation, to move from the stop $\#(k-1)$ to stop $\#k$. The shortest distance between these stops is a virtual/utopian line length $d_{\text{virt}}^{\langle k \rangle}$ (the superscript implies that the passenger is moving to this indexed stop). An average speed of the transporting vehicle at the route is known, so a virtual time interval taken for passing from the stop $\#(k-1)$ to stop $\#k$ is known as well. Denote it by $t_{\text{virt}}^{\langle k \rangle}$. Surely, virtual magnitudes $d_{\text{virt}}^{\langle k \rangle}$ and $t_{\text{virt}}^{\langle k \rangle}$ cannot be straightforwardly used for calculating tariffs because they correspond to an ideal case that is practically rarely possible (the road cannot be a straight line, and traffic jam happens). Therefore, denote a factual distance between the two stops by $d_{\text{fact}}^{\langle k \rangle}$. A factual time interval taken for passing this distance is $t_{\text{fact}}^{\langle k \rangle}$. Whichever the stops, route, or vehicle are, inequalities $d_{\text{fact}}^{\langle k \rangle} > d_{\text{virt}}^{\langle k \rangle}$ and $t_{\text{fare}}^{\langle k \rangle} > t_{\text{virt}}^{\langle k \rangle}$ are certainly always true.

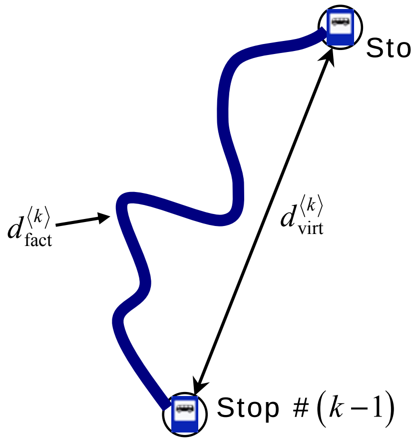

Figure 2. Virtual and factual distances between two stops of a route

There are a lot of other factors on charging fares, which are more implicit or latent [11]. Apart from reduced fares, they are vehicle type and route mode (normal one or night route, circular or prolate route). These ones are regarded as a definite tariff initial rate.

Calculation of tariffs. Formally, a fare payment for moving from the stop $\#(k-1)$ to stop $\# k$ by a definite tariff is

$$p_{\text{fare}}^{\langle k \rangle} = \alpha_{\text{tariff}} \cdot \psi_{\text{tariff}} \left(d_{\text{fact}}^{\langle k \rangle}, d_{\text{virt}}^{\langle k \rangle}, t_{\text{fact}}^{\langle k \rangle} \right) \tag{1}$$

by a given function ψ_{tariff} and fare reduction coefficient $\alpha_{\text{tariff}} \in (0; 1]$, where virtual time interval $t_{\text{virt}}^{\langle k \rangle}$ should not influence. It is useful to calculate a distance that would be an average of $d_{\text{fact}}^{\langle k \rangle}$ and $d_{\text{virt}}^{\langle k \rangle}$. This is a distance-to-pay magnitude. What should it regard? Clearly, if $d_{\text{fact}}^{\langle k \rangle}$ is longer than a half of a circle then it is unreasonable to count that „as is" (reasonability holds for a transport company, but not for passengers). In order to deserve trust of passengers, distance-to-pay is

$$d_{\text{2pay}}^{\langle k \rangle} = \frac{d_{\text{fact}}^{\langle k \rangle} + d_{\text{virt}}^{\langle k \rangle}}{2} \quad \text{for} \quad d_{\text{fact}}^{\langle k \rangle} \leqslant \frac{\pi d_{\text{virt}}^{\langle k \rangle}}{2} \tag{2}$$

and

$$d_{\text{2pay}}^{\langle k \rangle} = \frac{\pi + 2}{4} d_{\text{virt}}^{\langle k \rangle} \quad \text{for} \quad d_{\text{fact}}^{\langle k \rangle} > \frac{\pi d_{\text{virt}}^{\langle k \rangle}}{2}. \tag{3}$$

However, an exception exists if there is an impassable obstacle on a virtual way between two stops (Figure 3), where it is reasonable to count a distance-to-pay as

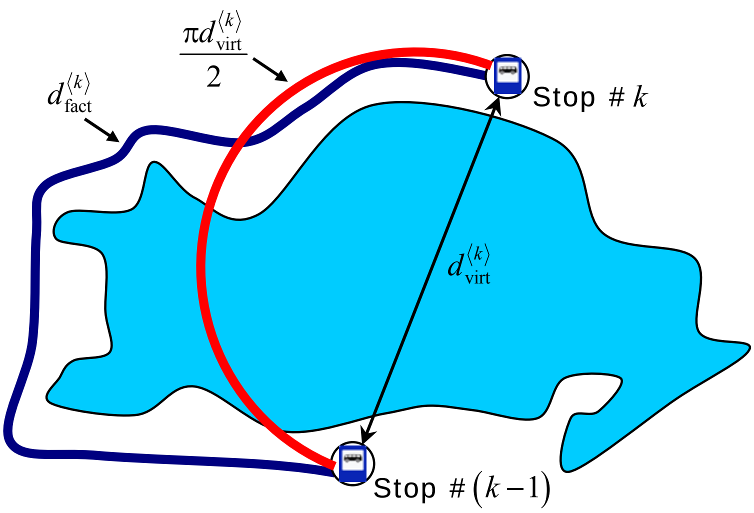

Figure 3. A case when calculation of the distance-to-pay by formula (3) is unfair due to an impassable obstacle on a virtual way between two stops (a river without a bridge, mountain without a tunnel, yard, vehicle fleet, residential area, police station, military facilities, etc.)

$$d_{2\text{pay}}^{\langle k\rangle} = \frac{d_{\text{fact}}^{\langle k\rangle} + d_{\text{virt}}^{\langle k\rangle}}{2} \quad (4)$$

regardless a ratio between $d_{\text{fact}}^{\langle k\rangle}$ and $d_{\text{virt}}^{\langle k\rangle}$. Then, instead of (1), the single stop fare payment could be stated as

$$p_{\text{fare}}^{\langle k\rangle} = \alpha_{\text{tariff}} \cdot \psi_{\text{tariff}}\left(d_{2\text{pay}}^{\langle k\rangle}, t_{\text{fact}}^{\langle k\rangle}\right). \quad (5)$$

Note that the function ψ_{tariff} in (5) does not contain any products of $d_{2\text{pay}}^{\langle k\rangle}$ and $t_{\text{fact}}^{\langle k\rangle}$. It may be, however, nonlinear with respect to those variables, i. e. terms like $\left(d_{2\text{pay}}^{\langle k\rangle}\right)^2$ and $\left(t_{\text{fact}}^{\langle k\rangle}\right)^2$ are admissible in constructing such a function. For getting rid of units of measurement, we normalize those variables: use $d_{2\text{pay}}^{\langle k\rangle} / d_{2\text{pay}}^{\langle \max\rangle}$ and $t_{\text{fact}}^{\langle k\rangle} / t_{\text{fact}}^{\langle \max\rangle}$ instead of $d_{2\text{pay}}^{\langle k\rangle}$ and $t_{\text{fact}}^{\langle k\rangle}$, respectively, where $d_{2\text{pay}}^{\langle \max\rangle}$ and $t_{\text{fact}}^{\langle \max\rangle}$ are maximal magnitudes on the given route (otherwise, they may be the total length of one direction and the total time taken for this length). Finally, the single stop fare payment is stated as

$$p_{\text{fare}}^{\langle k\rangle} = \alpha_{\text{tariff}} \cdot \psi_{\text{tariff}}\left(d_{2\text{pay}}^{\langle k\rangle} / d_{2\text{pay}}^{\langle \max\rangle}, t_{\text{fact}}^{\langle k\rangle} / t_{\text{fact}}^{\langle \max\rangle}\right). \quad (6)$$

If a passenger is transported for K stops, $K \in \mathbb{N}$, then the fare payment is

$$p_{\text{fare}}^{\langle k_1, k_2\rangle} = \sum_{k=k_1+1}^{k_2} p_{\text{fare}}^{\langle k\rangle} \quad \text{by} \quad k_2 - k_1 = K. \quad (7)$$

It is crucial to indicate integers k_1 and k_2 as the payment differs from stop to stop.

A scheme of executing flexible fare payments and their control

Required equipment, devices, and software. For executing flexible fare payments (7) by (6), as well as counting them, GPS navigators and special WiFi-like hotspots (fare-spots) must be mounted on the transporting vehicles. GPS navigator with software on an additional microprocessor controller will allow registering the elapsed time $t_{\text{fact}}^{\langle k\rangle}$ and passed distance $d_{\text{fact}}^{\langle k\rangle}$. The virtual line length $d_{\text{virt}}^{\langle k\rangle}$ is in memory of the microprocessor controller.

There are two ways for passengers: to use either smartphones with the corresponding standardized application (for this public transport system) or just smart cards similar to bank cards. In the case of cards (let them be called fare-cards), the vehicle must have a few card readers (apart from ticket-stamping machines).

Software at the vehicle, controlling the elapsed time and passed distance, will process also data of those passengers using smartphones. The standardized application on the smartphone is provided for connection with fare-spots and the passenger's control of one's account (balance, available tariffs and the current tariff, fares, costs, used routes, statistics of stops, speed, the passed distances and the spent time).

Passenger's account. Once the passenger has decided to use or try the prepaid service, one should register an account on the corresponding website of the public transport system. The passenger can manage one's account as follows:

1) to replenish amounts of pre-payments;

2) to select available tariffs;

3) to prohibit undesirable tariffs (for instance, to prohibit fast lines along with tuning notification signals on the smartphone application, which subsequently gives a list of available tariffs and will warn if the passenger tries to get on a vehicle of the fast line);

4) to select available routes;

5) to prohibit undesirable routes (for instance, to prohibit a route along with tuning notification signals on the smartphone application, which subsequently gives a list of available routes and will warn if the passenger tries to get on a vehicle at one of the prohibited routes);

6) to make loans (which are very convenient in casual situations, e. g. for night tariffs, although they may appear non-prepaid);

7) to set up amounts of loans (per month, per year, per some period of time);

8) to see statistics of one's passages (covered distance, time intervals of passages and their histogram, time spent on passages, favorite routes);

9) to make a rough quasi-optimization of costs by selecting more appropriate tariffs based on the statistics.

Reading and writing on passenger's account. The passenger can use the prepaid service with either buying a fare-card or installing the prepaid service standardized application on one's smartphone. When the passenger using a fare-card gets on the vehicle, the fare-card is put against a card reader (the time of putting is written on it) and a standard amount of fare payment is read off. This amount is equal to a maximal fare payment $p_{\text{fare}}^{\langle \max\rangle}$ by the given tariff (say, it is 3.20 zł on common line in Gdynia). When the passenger has ridden for K stops (from the stop $\# k_1$ to the stop $\# k_2$) and walks out of the vehicle, the fare-card is put against a card reader once again and an amount

$$a_{\text{fare}}^{\langle +\rangle} = p_{\text{fare}}^{\langle \max\rangle} - p_{\text{fare}}^{\langle k_1, k_2\rangle} \quad (8)$$

is written back on the fare-card. If this is not done (e. g., the passenger, walking out of the vehicle, just forgot to do that), the passage of K stops remains paid as a maximal fare $p_{\text{fare}}^{\langle\max\rangle}$ rather than payment (7). Such situation is excluded for the smartphone that pays „itself" the correct payment (7) via a fare-spot (Figure 4).

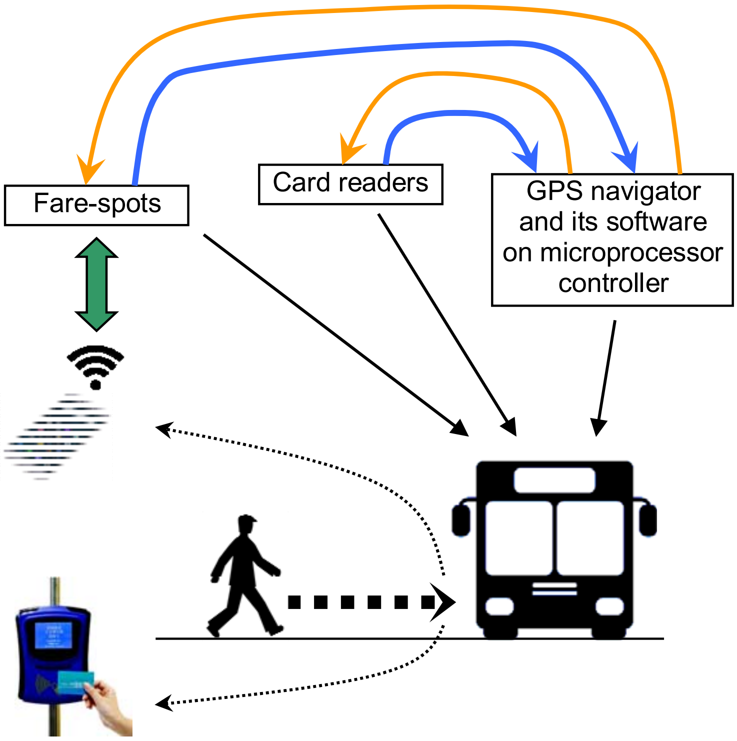

Figure 4. A scheme of executing flexible fare payments in two ways

For appropriately reading and writing on passenger's account, the fare-spot signal range should be of a few meters. As the vehicle takes off a current stop (that is spotted with the vehicle's GPS navigator), counters for the factual distance and time interval taken for passing this distance are started. While riding, the counters are currently seen in the application on the smartphone, as well as the current total amount of fare payment (similar to taxiing). When the passenger walks out of the vehicle, the fare-spot signal drops to a definite level showing that the passenger is outside the vehicle. Then, right after that moment, the passage and its fare is complete.

Work of fare payment controllers. Note that if the smartphone is turned off deliberately (to stop counters for getting a lower fare payment) and then, ahead of the final stop (walking-out), is turned on again, controllers of the elapsed time and passed distance will display an error. Eventually, GPS navigator will re-calculate the payment based on the factual distance and the internal time clock of the microprocessor controller. Therefore, such an occasion shall not be considered as a violation or passenger's delinquent action/behavior. A fine is only possible when controllers of fare payment detect that the smartphone has been turned off deliberately and currently it is still off. Personnel of fare payment controllers will have a special application on a smartphone or tablet showing current activity of all smartphones using the fare-spots on the given vehicle. So, they are not obliged to address to each passenger personally. In a way, such controlling of the smartphoned fare-spots can be accomplished by a special software. This software will inform about fare-spot violations. Driver or operator may be obliged to pay attention of those passengers who missed the fare-spots (turned their smartphones off) to that fact.

Fare-card is checked by those controllers whether it has been put against a card reader (the time of putting the fare-card is important, because, when the card is still not put against the card reader, the passenger might just have got on the vehicle and is only going to apply one's fare-card, so this is not a violation). Current number of the applied fare-cards is seen for the driver/operator also. However, it is not seen how many fare-cards are still non-applied.

Reasons for paper tickets. Paper tickets shall not vanish. A smartphone can have an accumulator discharge, or its operating system may have no support for the prepaid service standardized application, or a fare-card is lost. Thus, the third possibility to take a ride must exist. This is to buy a paper ticket (single ride, 24-hour, 72-hour fares, a month fare, etc.), wherever it is on sale. Besides, the prepaid service with using either smartphones or fare-cards may be unacceptable or incomprehensible for some aged people.

Conclusion

The suggested flexibilization in tariffing for passages is a step into further automation of public transport systems. Flexible or smooth fares are believed to motivate passengers for actively using one-stop passages (or passages for a few stops, not long distances) and to gain their trust. The work of fare payment controllers will be much simplified.

Of course, some demerits of the tariff flexibilization exist:

1) mounting fare-spots, card readers, and GPS navigators with microprocessor controllers requires considerable time and financial resources;

2) developing software for GPS navigators, management system (including main website of the public transport system), application for the smartphone, firewalls for protecting passengers' accounts also requires considerable time and financial resources;

3) before getting started with flexible tariffs on smartphones and fare-cards, testing the new system takes considerable time and human resources;

4) in a few months or even years, the total income of a public transport system is expected to decrease.

Surely, economical appropriateness here contradicts consumer acceptance and trust. But the income decrement is expected to vanish after the starting period because cheap one-stop passages are balanced with „heavier" passages (e. g., more active usage of night rides, two-stops or a-few-stops rides, passages for distances beyond the city like in Gdansk, Sopot, Gdynia).

Moreover, there are many benefits of the tariff flexibilization:

1) no gaps in fares;

2) much easier grasp of the public transport rules (actually, it is automatic);

3) passenger's independency of not knowing specific rules;

4) paying fairs is either automatic (by smartphones) or by simple action with a fare-card;

5) work of fare payment controllers is simplified;

6) drivers/operators are obliged to sell less paper tickets;

7) it should be easier to optimize tariffs as true total statistical data are available.

These ones are a stronger reason for implementation. Big cities, like Warsaw, can try the scheme in Figure 4 at least partially.

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