A MODEL OF THE ACCIDENT PROCESS AS A TOOL TO DEVELOP INDICATORS FOR TRANSPORTATION SYSTEM SAFETY AND TRAFFIC RISKS

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ABSTRACT

This paper deals with the development of indicators used in controlling the safety performance of a transportation system. Because of the very large and complex nature of transportation systems, effecting any changes proceeds very slowly. In addition, changes in the control variables by countermeasures generally have an output response that can only be observed after a rather long period (slowness of accident registration).

Decision makers need indicators that detect changes at an early stage in order to anticipate developments in the output of the transportation system. In order to control the safety of the system, they need knowledge about the relation between the changes brought about by possible countermeasures and the effects thereof. However, causal relations between countermeasures and output indicators are too complicated. What is needed is a breakdown of the total process into subprocesses and a theory explaining the effects of attributes of countermeasures on each of these subprocesses.

This paper discusses a structure of subprocesses that facilitates the development of process indicators that can be linked up with the theories relevant for the subprocesses. These process indicators and the relevant theories should have sufficient predicting force for the effect of countermeasures.

> "One accident with one death is
> a tragedy for those concerned;
> one accident with ten or more
> deaths is a disaster; one million
> accidents a year with 2,000 deaths
> and 60,000 injured is a statistic".

1. INTRODUCTION

The transportation system, in its present form and function, is in fact the work of monodisciplinarian scientists and decision makers. Town and transportation planners decide which roads should be built and where, traffic experts decide how the roads should be designed, road builders decide how these roads should be constructed and of which material. Vehicle experts decide how vehicles should be designed and function, behaviour scientists and legal experts decide how the roads and vehicles should be used.
Strictly speaking, everybody operates independently, more or less, without enough knowledge of the others' fields of interest. The road users, limited in his possibilities to perceive, decide and act, has to function in a system in which the coherence of the elements (road, vehicle, traffic and surroundings) often is not enough taken into consideration.
The lack of coherence of the elements of the transportation system not only influences the scope of the aim, the "mobility-production", such as travel miles, travel time, etc., but also brings about undesired "by-products" or adverse effects, such as unsafety.

We often talk about transportation system and the traffic system, but we do not always realise what the consequences are of applying these system conceptions.
Probably the most important characteristic of system thinking is to consider the relevant interactions between the elements or entities in a system.
These interactions are more important than the properties of the element itself.

Since every system is a subsystem of a larger one (the public transport system is a subsystem of the transportation system), choosing the right boundaries of the system model in fact settles the matter.
This requires a structural analysis of problems before starting research and before thinking of control possibilities (counter-measures). In making the problem analysis, the following questions can be considered:

- What is the process to be controlled?
- Wat for and why should it be controlled?
- How should it be controlled?
- Who controls what and where?

In the post-industrial period, in which the western world finds itself, problematic situations and problems are not absolute, but arise from the question: To what extent can the undesired negative "by-products" caused by our individual behaviour be accepted?
We must realise that society seems to accept the fact that 2,000 people are killed every year in Holland and 50,000 fatalities occur in the USA, and that all other harm caused by the transportation system is accepted as an inevitable fact. If we resign ourselves to accepting this as an act of God, the safety problem is solved from the point of view of the society.

As the adverse effects of the transportation system, such as unsafety, become more and more unacceptable, we have to begin searching for an answer to the first question: "What is the process to be controlled"; what is the nature of the phenomenon that is unacceptable.

2. TRANSPORTATION (UN)SAFETY AS A MULTICAUSAL CHANGE PHENOMENON

Transportation unsafety is a phenomenon that does not occur in every journey. Each journey does, however, involve air pollution, noise and energy consumption. The extent of this depends, among other things, on the modes of transport, the road, the speed, and the distance that is covered.

An accident involving casualties occurs at a given place on a given road, with given vehicles, to given persons, with a given traffic structure and in given weather conditions. However, there are no places where accidents always occur; there are no vehicles that are always involved in accidents; there are no persons who always cause accidents; nor are there any weather conditions that always lead to accidents.
Yet, accidents happen; people are killed and injured. Therefore a coinciding of road, vehicle, traffic and human characteristics and circumstances is apparently needed to cause accidents.
The chance of such a critical coinciding of characteristics and circumstances occurring is not the same always or everywhere. Moreover, the consequences of accidents are not always the same but depend, among other things, on the type of collision (for instance car with pedestrian) and the human tolerance of the persons concerned.

If we analyse a traffic safety problem on a statistical level, this implies that we concentrate on average or central tendencies. The question now arised whether or not this gives the relevant information about the real nature of the problems we want to control. The risks on any trip from A to B are not equally spread over all parts of the trip. We might find that the risks per travel mile of one part is five or ten times higher than another part of the trip. The average risk of the total trip per travel mile has no significance at all for control purposes, especially when the low risk part is rather large, The same accounts for big differences in time, ages, and the like.

Therefore a description of transportation unsafety requires indicators taking into account the nature of the accident phenomenon.

3. MODEL OF THE ACCIDENT PROCESS

We live at a time in which social problems are vast, while the resources and means seem to be getting scarcer and scarcer. It is very important, therefore, that effective countermeasures are taken. This means that the decision makers need knowledge and information on the effectiveness of the potential countermeasures.

As part of a policy, countermeasures considered effective are applied in an endeavour to attain certain goals. We now come to the second question: "What for and why should it be controlled?".

The countermeasures and the goals are adjusted to each other by the decision makers. This implies, as such, that the decision makers employ a theory or a theoretical model of the causal relationship between the changes brought about by the countermeasures and the effects thereof.

In fact the decision makers have to choose the correct control mechanism. This concerns the third question: "How should it be controlled?".
Controlling a complex, mass system such as the transportation system proceeds, in fact, very slowly.
One can compare control of the transportation system with the steering of a fully loaded mammoth tanker. If the wheel of such a vessel is swung right round, the effect (the output) will not become noticeable for some time. There are two reasons for this:
a. the slow response by the tanker and the causal lag (the slowness of accident registration);
b. the limitation of human perception abilities in noting slow (slight) changes (the limitations of statistical analysis methods for disclosing small changes in the pattern of accidents). The moment the changes in output are observed, it is often too late both on the tanker and in the transportation system to take effective, corrective action.

Masters of giant tankers, therefore, do not respond much to changes in the vessel's course (output variable; accident statistics), but anticipate changes in output by responding to data on input and intermediate processes (input and process indicators), such as position of helm, speed, direction and speed of currents. This is possible because they have sufficient knowledge and comprehension of the relationship between control variables and process variables, and the influence this has on changes in output. They do not wait, therefore, until the moment the output (change in course) manifests itself. Ships' captains have acquired this knowledge from real world experience or simulations in which the relationship between control variables (via process variables) and output variables was examined or simulated under different conditions (speed, current, wind). This form of control does also require regular "position finding" in order to verify and adjust that from "dead reckoning".

In terms of the transportation system, this means that output indicators have to be measured in order to verify the predicted relationship between process indicators and output indicators (increase of knowledge).
In the same way as described above, control of the transportation system can also be focused on changing the input of the system, for instance on changing the need or demand for journeys in general or for specific modes of transport.

Therefore, indicators for describing the effects of countermeasures must link up with the (theories on) the subprocesses within the transportation system which are relevant to road safety.
In addition to process indicators and output indicators, input indicators should be measured as well.

In other social problems, such as unemployment, the debate on possible countermeasures largely involves differences in theory or even the lack of theories on subprocesses. These are mainly differences in theories on human behaviour in relation to the other system elements.

Transportation unsafety is the result of a complex process in the transportation system. A large number of variables (characteristics of the system elements) with many interactions, produce a complex network of relationships expressed in "system behaviour".
In this network of relationships, man as an element in the transportation system has the greatest number of degrees of freedom. His behaviour is, therefore, most difficult of all to predict. Theories on the overall process in the transportation system are therefore dangerous and misleading. Theories only have predictive force if all relevant subprocesses are distinguished. In other words, in order to be able to predict the effects of countermeasures, those subprocesses must be distinguished within the process as a whole. Countermeasures can have an opposite effect on the distinguished subprocesses.

In Figure 1 the accident process is shown schematically: starting in the social system from a certain activity, for example, paying a visit somewhere, one will travel with a certain vehicle via a certain route and according to a certain travel scheme (transportation system). One gets involved in traffic situations that effect a certain traffic behaviour and "provoke" this behaviour to a greater extent. For example, a road with wide lanes will provoke high driving speeds, even in a residential area. Whether a critical coincidence of circumstances arises, strongly depends on the "existence" of certain conditions and their predictability. But one's own traffic behaviour also plays a part in the approach to those circumstances. For example, a critical coincidence arises when a road user approaches an intersection at high speed, with cross-traffic approaching at the same time.
If anticipating is possible, because the road user recognises this critical coincidence in time, a normal braking manoeuvre can be carried out. If braking in time is not possible, an emergency manoeuvre is needed. This not only demands ability of reaction

and skill of the road user, but also a sufficient friction coefficient between the road surface and the vehicle tyres, room for pulling out and adapted steering, and sufficient braking characteristics of the vehicle.

If the emergency manoeuvre is successful, an incident (or conflict) arises. The consequences are: getting frightened and, depending on the presence of other road users or vehicles, a chain disturbance, that is to say, the accident vehicle causes a new critical situation for approaching vehicles. If the emergency manoeuvre fails, an accident arises. The victims of the accident can be not only the considered road user himself, but also other road users.

On the one hand, the consequences (in terms of injury) depend on the forces that affect people during the collision and on human tolerance. Human tolerance is not the same for everybody. Young people have a far greater human tolerance than the aged. High death figures of aged people (in traffic and in the private sphere) can be explained better by low human tolerance than by restricted perceptive capacity or reaction ability. Such restrictions are mostly compensated by "careful" behaviour.

At last there is the recovering phase. It is a pity that not all the survivors will recover fully. Too little attention is paid to this aspect. Each year new permanently disabled persons have to be added as statistics to the data of the previous years.

In Figure 1 the feed-backs between the phases are not taken into consideration. There are also more feed-forwards possible in the model. In het example of traffic lights some of the feed-backs are given.

4. A START TO DEVELOP PROCESS AND OUTPUT INDICATORS

The impression may be created that it is a simple matter to supply sets of process indicators and output indicators suitable for general use. Unfortunately it is more complicated than this. Indicators must be a criterion belonging to a stated problem. We rarely study the transportation system as a whole, but subsystems instead. Even so, we tend to focus on aspects of subsystems, such as traffic hazards at intersections, the unsafety of pedestrians, cyclists, etc. For correct use of the indicators, the choice of the (sub)system boundaries is very important.

This may be illustrated by the following example. See Figure 2. A road authority has in its road network an intersection where a comparatively large number of accidents occur, causing many casualties (problem related to output variables). Actually, the observation of the critical coincidence of circumstances by the road users is defective. This is apparent from faulty or even non-anticipating traffic behaviour that people not always decelerate sufficiently and sometimes not al all (problem related to process variables). The authority thinks it can solve the problem by installing traffic lights (countermeasures). What does such a countermeasure bring about on the accident process? See Figure 1 again and also Figure 3.
Installing traffic lights at one intersection will not deter road users from making as many journeys, nor will they change over to a different mode of transport. What they may do is to select a different route to avoid traffic lights. We must therefore know the input indicators for the intersection, for instance, the number of approaching vehicles. But, we must look also beyond the intersection for other roads (extension of system boundaries) where the input indicators increase (more traffic on the roads). The effect of installing traffic lights in the phase of route selection can be fewer approaching vehicles.
The effect of fewer approaching (and hence passing) vehicles in the phase of traffic behaviour "provoked" in advance may be higher speeds.

The effect of higher speeds in advance may be poorer observation of critical coincidences so that these are anticipated too late or not at all. An emergency manoeuvre (emergency stopping) may then still prevent a collision, provided the road surface there has sufficient skidding resistance.

There are a number of hypotheses which are important for determining indicators from this example.
- Fewer approaching vehicles, when traffic lights are inflexibly regulated, may even result in more people driving through the red lights, often with very serious consequences. All phases of the accident process then have a negative rating.
- Higher speeds in advance without anticipatory behaviour influence the success or failure of the emergency manoeuvre.
- Traffic lights may bring about a different kind of critical coincidence of circumstances, not because of the intersecting traffic but because of the queue at the traffic light that is being approached. The location of the critical coincidence "moves" downwards in Figure 3 with regard to Figure 2. Failing anticipation and the emergency manoeuvre (including evasive action) will cause another type of collision: head-to-tail instead of flank impacts.
- The effects of head-to-tail impacts are often less serious than those of flank collisions (crumple zone).

In this example of installing traffic lights at an intersection, the site of the critical coincidence of circumstances is determined by the intersection. However, there are also critical coincidences without a fixed location, such as at the end of a (variable) queue, with overtaking manoeuvres in a traffic flow, in a traffic flow with short-following headways, and so on.

From the example above we learn that theory, hypothesis and process variables necessary for indicators and the general accident model go hand in hand.

How are these research elements related to each other? See Figure 4. On the operational level we can make statistical models of the indicators. We must realise that on the operational level there are no causal relations, so we need the transformation to the theoretical level of the different process phases.
From these phases we can choose the right variables and process indicators on the operational level.
The generalised, structural model gives the framework for the different process phases.
For controlling a system and thus for choosing the right counter-measures we need knowledge on the theoretical level related to the general framework.

If we want to know the effects of countermeasures, we need to develop the following kinds of indicators in the above example:
- Input indicators, for instance, approaching vehicles (per unit of time);
- Process indicators for "provoked" traffic behaviour in advance (for instance, speed), for observing critical coincidence of circumstances (for instance, mental activation level), for "anticipatory" traffic behaviour (for instance, deceleration), for emergency manoeuvring (for instance, deceleration and/or change of course), for crash behaviour (for instance, impact decelerations);
- Output indicators (for instance, type of accident, number of vehicles in accidents, number of persons in accidents, number of casualties and number of permanently disabled).

On the question of what are the best performance indicators to describe the safety aspect of the transportation system, there is no general answer. Indicators are mostly used to make comparisons between countries, periods (before and after countermeasures), different categories of roads or road users, age groups, traffic situations, etc.
The choice of the relevant sets of indicators is dependent of the problem setting and the proper questions raised from the problem analysis.

5. EXAMPLE OF A SET OF OUTPUT INDICATORS

Output indicators for transportation unsafety mainly express a kind of risk, that is to say, a chance on an accident or a chance to be killed per inhabitant, per persons-kilometres of travel, etc. Herewith, we have to consider carefully the fact that the numerator and the denominator are in all cases compatible.

An output indicator, such as $\frac{\text{number of casualties}}{\text{number of vehicle kms}}$, is not unambiguous. One vehicle may have more than one occupant in an accident (accident persons) and one accident may involve several vehicles (accident vehicles).
An indicator, such as $\frac{\text{number of fatal accidents}}{\text{number of vehicle kms}}$, can also give a badly distorted picture. For instance, a bus has a comparatively large number of fatal accidents per vehicle kilometre (in The Netherlands about 4 times higher than a private car), the victims mostly being the other parties, especially pedestrians. This does not mean, however, that replacing buses with cars would make the roads safer. The high occupancy of buses (an average of twenty persons in The Netherlands) and the low occupancy of cars makes one bus equivalent to about ten cars. Ten cars together will cause more casualties than one bus. (This does not pertain to empty buses or buses with low occupancy.)

Sets of indicators are mostly needed in order to describe the phenomenon. In Figure 5 an example is shown of such a set of indicators.
The indicator $\frac{\text{number of casualties}}{\text{number of persons involved}}$ gives the link from the transportation system to the social system and facilitates a comparison with other threats in society.
Every indicator has a certain significance, that is it links up with certain theories and models. The indicator for accident occupancy, for instance, $\frac{\text{number of persons in accidents}}{\text{number of vehicles in accidents}}$, links up with a theory claiming that the number of occupants influences the driver's possibilities of perception and may even influence the "provoked" traffic behaviour in advance and the "anticipatory" behaviour (in an adverse sense).

The indicator for severity of accident, for instance, $\frac{\text{number of casualties}}{\text{number of persons in accident}}$, links up with theories of human tolerance. For example, if old people are involved in an accident, this indicator will turn out very unfavourable (low human tolerance).

This set of indicators provides the possibility of obtaining a clear interpretation of the unsafety of the whole transportation system on the basis of various problems and from various approaches, and at the same time provides a framework and an incentive for the planned collection of data.
Specifications of these indicators are necessary, and we have to break down the transportation system into subsystems, such as the various modes of transport, different age groups, various smaller or bigger areas (localities, regions, etc.), and the various types of confrontation, such as car/bicycle, bus/pedestrian, and so on. The same formula can be used for this purpose.

6. SUBJECTIVE RISK AND FEELINGS OF DANGER

Research in The Netherlands indicates that, especially in residential areas, many decisions regarding road safety are taken on the basis of the residents' feelings of danger and subjective risk. We must realise that traffic in residential areas is different from that in specific traffic areas.
In residential areas in The Netherlands, pedestrians account for about 40% of all journeys, while a high percentage of car journeys in such an area is homebased. This means that the same persons alternate between being pedestrians and motorists.
In the confrontation with motorised traffic the pedestrian is the most vulnerable, and in this role he also experiences the fear for accidents and feelings of danger. By voice in neighbourhood councils, he can put this experience before the local authority and use it as a means to press for countermeasures. They hardly realise that the countermeasures are then in fact adopted for them in their role of motorists.

Many voices are being heard asking for measures and indicators to be developed for subjective risk (that is fear for accidents and feelings of danger). There are also appeals to base road safety policy largely on subjective risk. But, before we can answer the questions about indicators, we have to start again with the first question: "What is the process to be controlled?"
Only if we have enough insight and theories about this phenomenon and about the way it works in the individual and collective decision process, we can start to develop indicators for subjective risk.

When we analyse this phenomenon of subjective risk or feelings of danger, we have to pay attention to the diversity in the way it appears. Situations regarded as subjectively risky are often objectively very safe. This is not surprising, because feelings of danger often have a favourable effect on the perception of critical coincidences and on "anticipatory" traffic behaviour.

In addition, feelings of danger depend upon the role one plays in the transportation system (pedestrian or motorist).

I think it is better to give the decision makers better tools to resist pressure from neighbourhood residents and to direct their interests in a different direction if necessary.
Process indicators linked up with theories that have prediction force for the output could be such a tool. By using these indicators, decision makers could base their policy on what they know and not (only) on public acceptance of their countermeasures.

7. CONCLUSIONS

o System safety is primarily a complex control problem.

o Knowledge must be structured in such a way that the decision makers can control the transportation system safety. Necessary conditions are: insight into and theories about relations between countermeasures and the effects thereof and process indicators with predictive force with respect to output.

o Output indicators must be measured continuously to determine if the right source is chosen and if the corrective actions are effective.

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* Only in Dutch

FIGURES

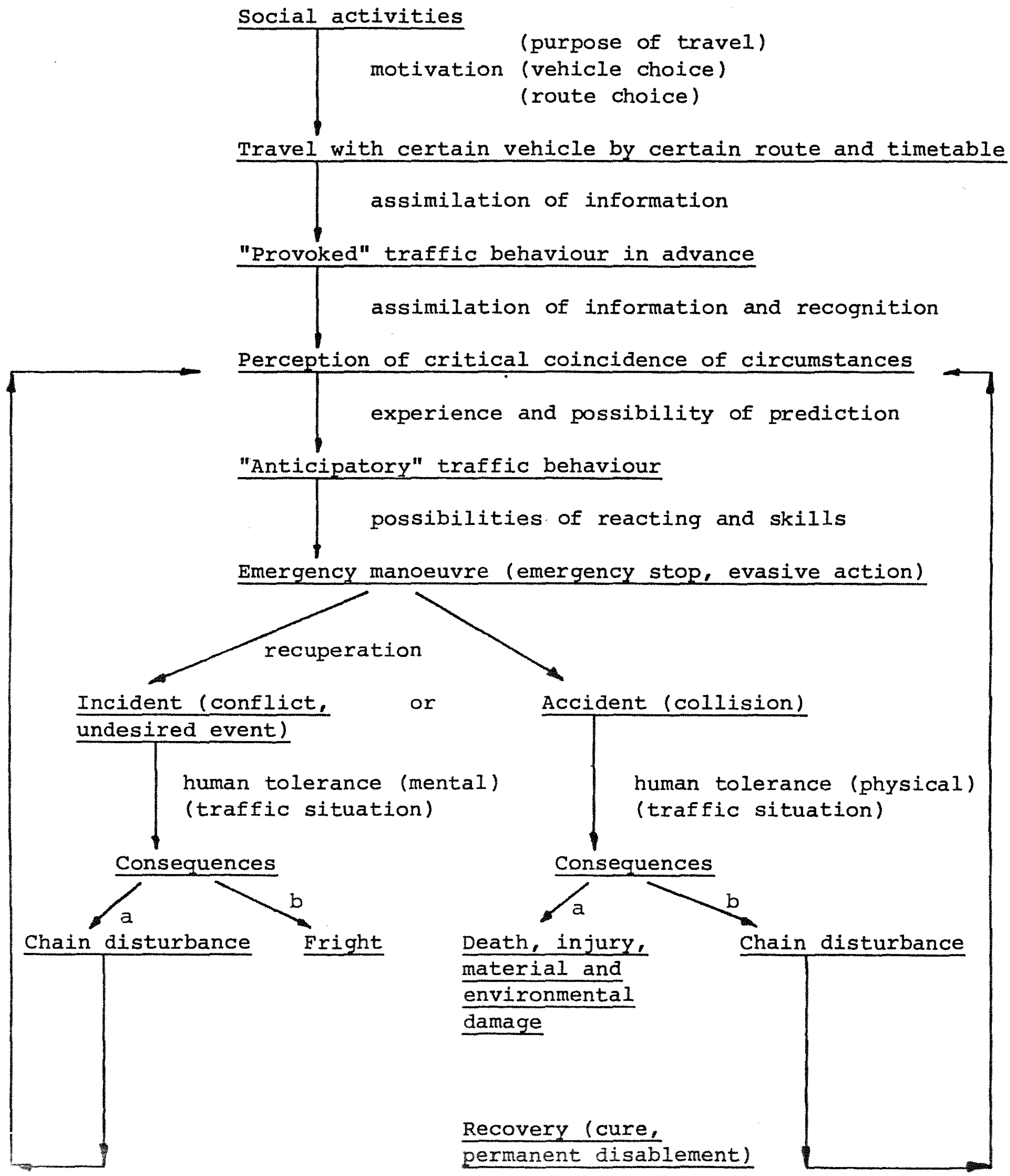

Figure 1. Model of the accident process.

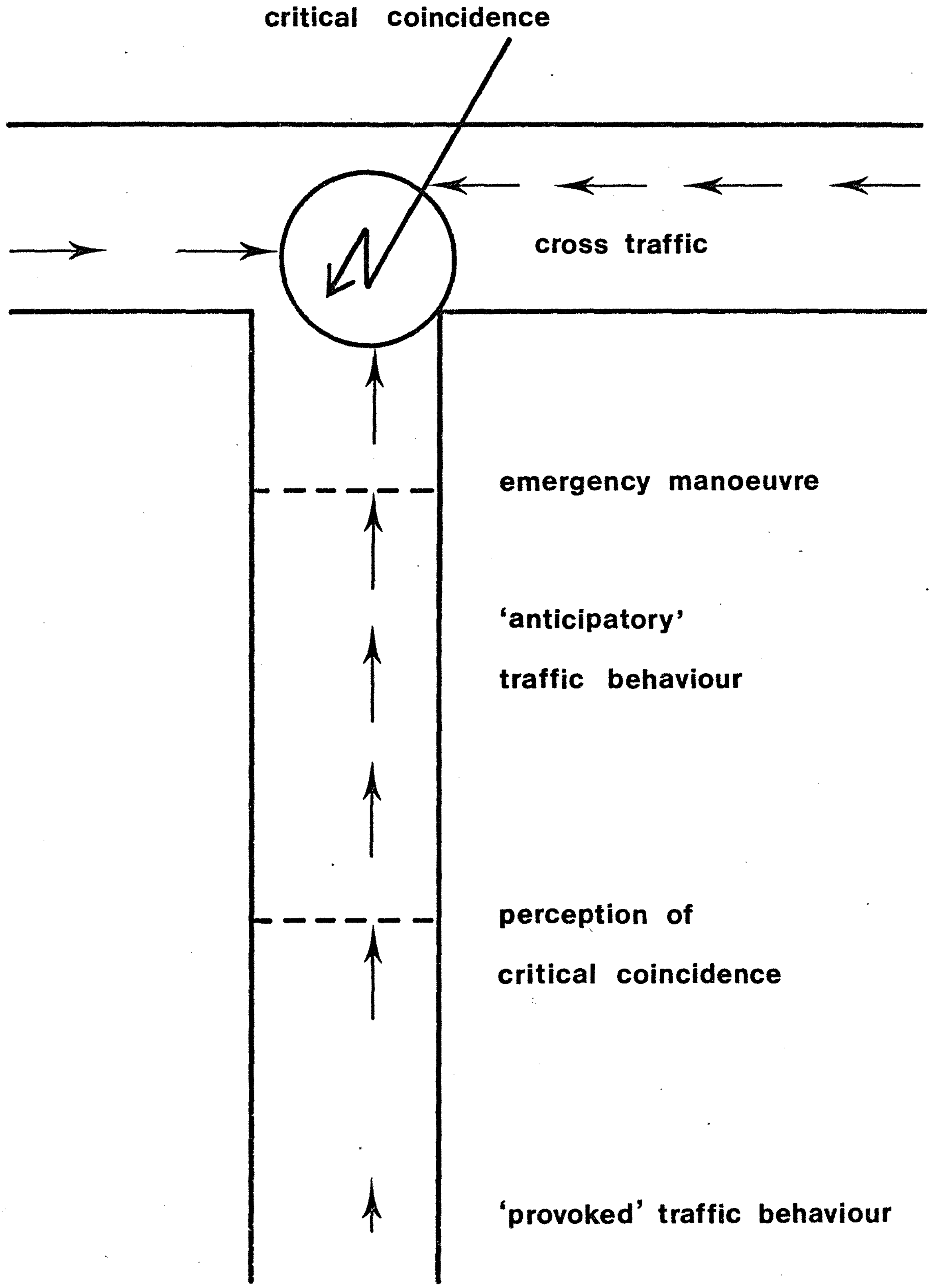

Figure 2. Accident process before installing traffic lights.

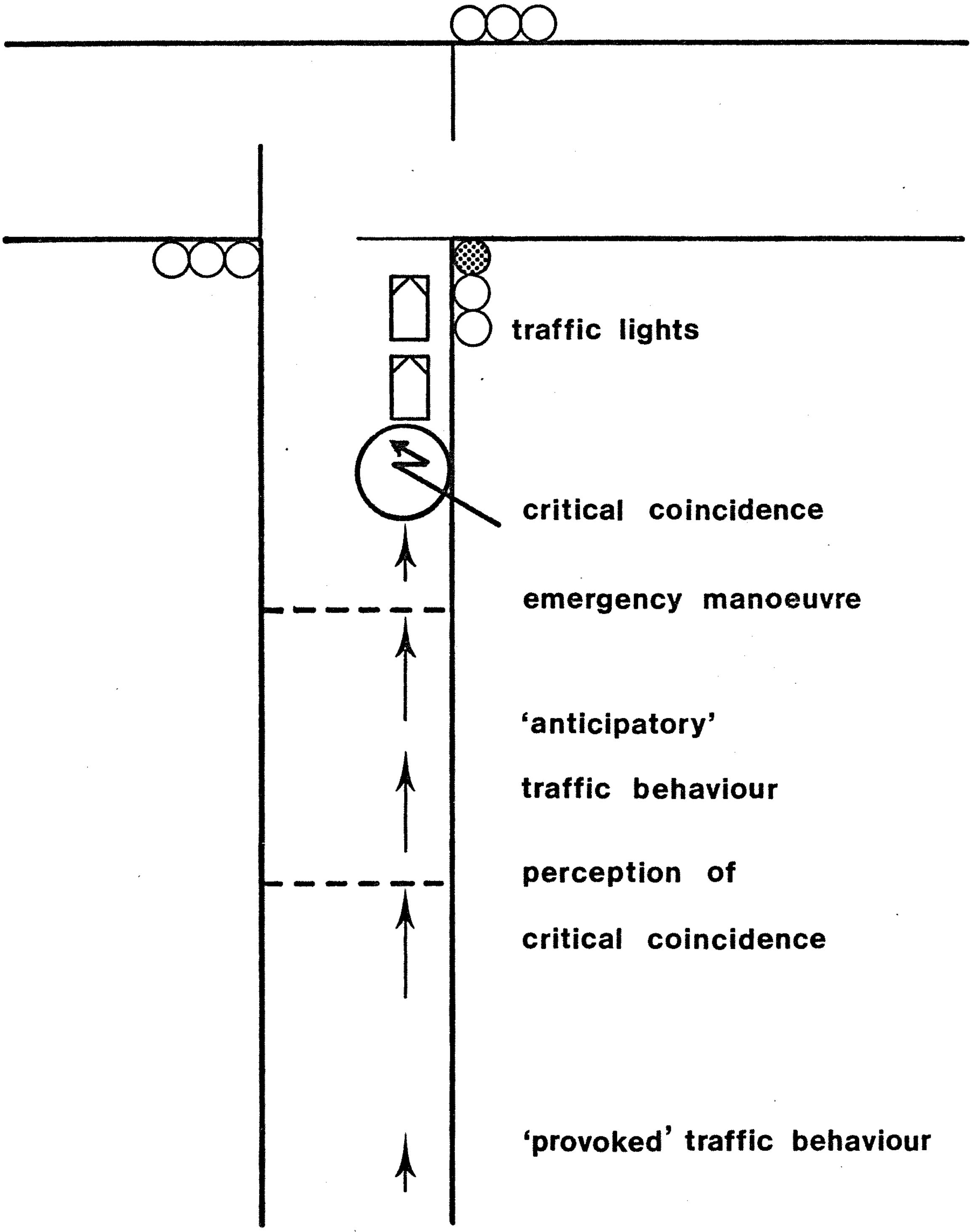

Figure 3. Accident process after installing traffic lights.

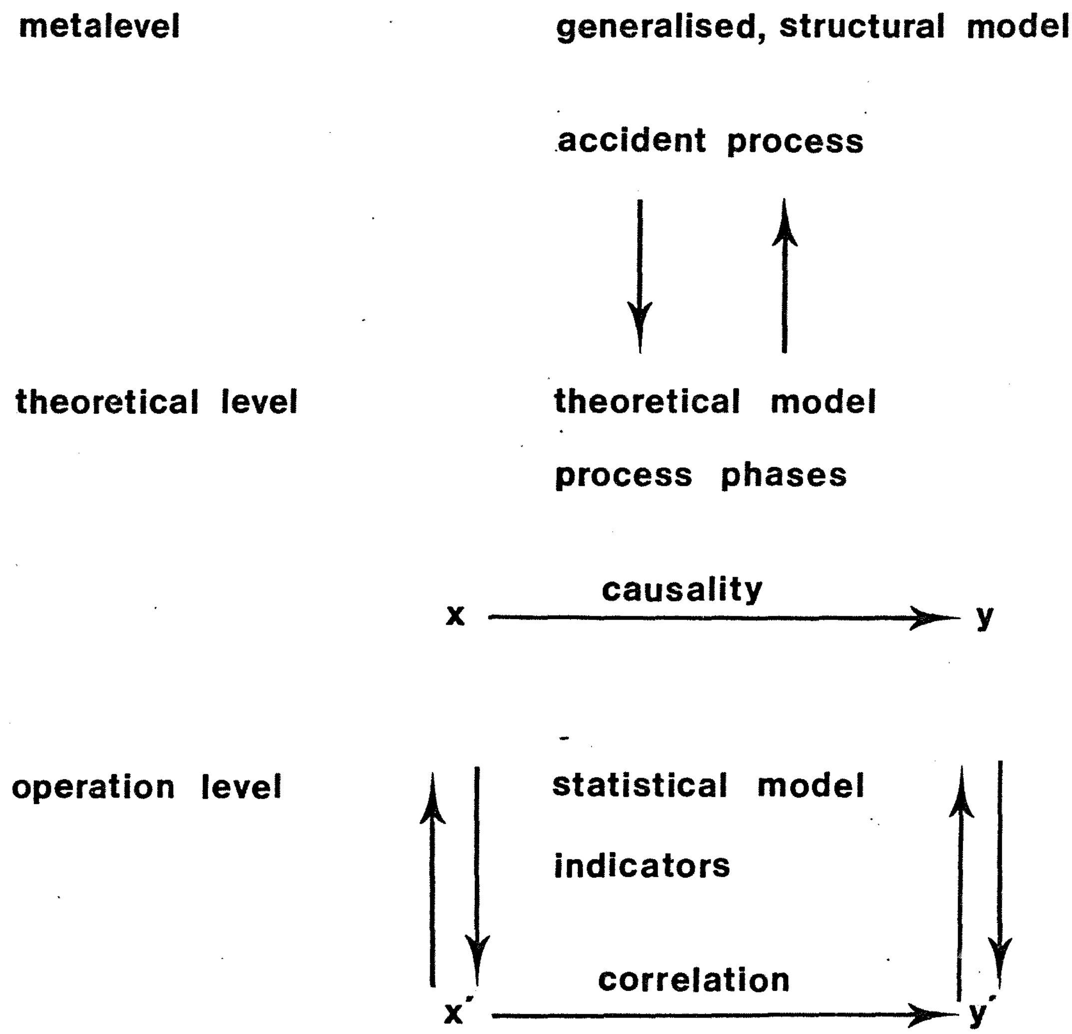

Figure 4. Relation between research elements of different levels.

General set (tautology):

$$\frac{\text{number of casualties}^{*}}{\text{number of persons involved}} = \frac{\text{number of traveller kms}}{\text{number of persons involved}} \times \frac{\text{number of vehicle kms}}{\text{number of traveller kms}} \times \frac{\text{number of accident vehicles}}{\text{number of vehicle kms}} \times$$

(total unsafety) (mobility) (occupancy) (accident complexity)

$$\times \frac{\text{number of accident persons}}{\text{number of accident vehicles}} \times \frac{\text{number of casualties}}{\text{number of accident persons}}$$

(accident occupancy) (accident severity)

Specific set for bicycle traffic:

$$\frac{\text{number of bicycle casualties}}{\text{number of bicyclists}} = \frac{\text{number of traveller kms on bicycle}}{\text{number of bicyclists}} \times \frac{\text{number of bicycle kms}}{\text{number of traveller kms on bicycle}} \times$$

$$\times \frac{\text{number of accident bicycles}}{\text{number of bicycle kms}} \times \frac{\text{number of accident bicyclists}}{\text{number of accident bicycles}} \times \frac{\text{number bicycle casualties}}{\text{number accident bicyclists}}$$

Other specific sets are possible for: other means of transport, various age groups, regions, lokations, confrontations.

*casualties: killed and injured; only killed or only injured.

Figure 5. Examples of a set of output indicators.