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Strategic location of eletronic monitoring equipment for interception of evasive flow in road networks

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RESUMO: No âmbito da fiscalização rodoviária, os equipamentos eletrônicos automatizados são capazes de ler as características dos veículos passantes, incluindo sua identificação, medidas, velocidade e peso. Embora tais equipamentos possam ser utilizados para criar malhas de monitoramento, os condutores podem, em muitos contextos, planejar suas rotas de forma a evitar a passagem por esses sistemas, sabendo a sua localização. Fluxos que podem apresentar tais tendências evasivas são, por exemplo, veículos intencionalmente sobrecarregados, furtados ou executando outras atividades ilegais. O impacto negativo desses fluxos pode ser minimizado com o uso de modelos de localização que considerem a tendência evasiva. Visto isso, este artigo apresenta um estudo de caso, no qual aplica dois modelos, que consideram o Problema de Captura de Fluxo Evasivo (EFCP), na malha rodoviária do estado do Pará. Como resultado dessa aplicação, conclui-se que dois postos de fiscalização de peso, posicionados de maneira otimizada, são capazes de reduzir satisfatoriamente o dano causado por veículos com sobrepeso na infraestrutura da malha analisada

PALAVRAS-CHAVE: Sistemas de transporte. Fluxos evasivos. Fiscalização. Interceptação. Malhas viárias.

ABSTRACT: In the context of road enforcement, automated electronic equipment are capable of reading the characteristics of passing vehicles, including their identification, measurements, speed and weight. Although such equipment can be used to create monitoring loops, drivers can, in many contexts, plan their routes in order to avoid passing through these systems, knowing their location. Flows that may exhibit such evasive tendencies are, for example, vehicles intentionally overloaded, stolen or carrying out other illegal activities. The negative impact of these flows can be minimized by using location models that consider the driver's evasive behavior. In view of this, this article presents a case study, in which it applies two models, which consider the Evasive Flow Capture Problem (EFCP), in the road network of the state of Pará. As a result of this application, it is concluded that two weight inspection posts, optimally positioned, are able to satisfactorily reduce the damage caused by overweight vehicles in the infrastructure of the analyzed network.

KEYWORDS: Transportation systems. Evasive flow. Enforcement. Interception. Road networks.

1. Introduction

Motor vehicles in illegal conditions traveling on Brazilian highways represent several types of safety risk [1], to transport infrastructure [2] and to the economy [3]. Such conditions include excessive speed, non-licensing, overweight, transportation of incorrectly packaged special or dangerous cargo, among other situations of illegality. In addition, in the strategic planning of transport systems and in the management of the road network, it is essential to know the nature of road flows in a given region, so that investments can be prioritized and traffic inspection carried out. Both tasks are associated with the need to directly assess the characteristics of vehicles in transit.

Collecting road flow data directly, however, is not a trivial task for Brazilian entities. Brazil's road network is extensive, totaling 1,719,991 km of highways [4]. Even considering only the highways under federal jurisdiction, it is a network of 75,744 km, through which flows of the most varied types pass, with different origins and destinations.

Therefore, the use of electronic road monitoring equipment has great potential for controlling traffic on highways. These have the ability to verify important characteristics of the vehicles that pass at a certain point without the flow being interrupted. Among the functionalities of these sensors is the measurement of the speed [5], reading license plates, measuring the overall dimensions of the vehicle, weighing axles at high speed [2] and other vehicle identification systems [6].

Drivers who travel with their vehicles illegally, however, usually do so consciously [7, 8, 9]. This is because, traveling with overweight, or without the correct packaging of dangerous goods, for example, can bring profit to the transporter through the reduction of its costs (this particular profit is paid by society, through higher maintenance costs of the road network and greater risks to road safety). Thus, from the installation of monitoring and inspection equipment, transporters in an illegal situation, when they know their location, will seek to change their routes, in order to prevent their vehicles from being detected.

The relationship between the decision of the network planner – where to install inspection equipment – and the decision of the transporter in an illegal situation – to travel avoiding passing through these devices, gives rise to the formulation of the mathematical optimization problem, known as Evasive Flow Capture Problem (EFCP). [10, 11, 12] In this formulation, the aim is to identify the optimal locations to install surveillance sensors in such a way that the set of these systems minimizes the existence of unmonitored routes.

Through efficient planning of the distribution of monitoring sensors across the road network, considering such an evasive tendency, it is possible to create a "fence" of electronic devices, through which all flows in a given region are intercepted at least once. This type of application has great potential for national intelligence, allowing inspection systems to be established with great efficiency and little possibility of evasion. Furthermore, considering the evasive tendency does not significantly increase the number of equipment to be installed, but only optimizes the choice of locations to prioritize those that generate the greatest coverage of flows. [13]

In this context, the objective of this article is to carry out a case study on the road network in the state of Pará, based on the implementation of two models that consider the evasive tendency through inspection.

1.1 Method

With the intention of accomplishing the objective of this work, application of weight monitoring equipment location models, two steps were carried out: systematic literature review and implementation and application of the models - case study.

The first stage, a narrative and systematic review of the literature, was carried out with the aim of selecting which models would be most suitable for application in the Brazilian road network. In this context, works related to the themes were collected: location of inspection equipment, evasion by changing route and mathematical formulation of the EFCP and its solutions.

After such review, the methods proposed by Marković et al. [10] and Arslan et al. [14] were selected for the practical application of this work. These were implemented through the Python programming language and the use of the PuLP [15] and MIP libraries [16], respectively. The first step in this implementation was a thorough study of the equations and peculiarities of the models, in order to transcribe them into the chosen programming language. Later, personalized restrictions were inserted in the models, created by the authors in order to adapt the models to the reality of Brazilian highways.

Finally, the road network of the state of Pará was selected for the case study, which even with a low density of roads, has a relevant load flow for the northern region of Brazil.

2. Systematic review of inspection equipment location models

Unlike the traditional or narrative review, the systematic review is a more thorough methodology, which uses systematic search methods, with the aim of evaluating the applicability and relevance of each of the studies found. This procedure is intended to minimize the influence of the researcher in the selection of analysis papers, executing a selection process independent of their personal opinion. [17]

The first stage of this process was the formulation of the research question, which guided the research. The focus of this study was to cover the largest possible number of studies related to the subject and to find methods that used network data as parameters such as: traffic volumes, number of accidents, road geometry, nature of cargo flows, among others.

Subsequently, the criteria for exclusion and inclusion of studies were defined, such as the date of publication (only those published from 2012 onwards were considered), language (English or Portuguese), availability and relevance, measured based on publication date and number of citations. To carry out these searches, the Scopus, Scielo, Web of Science, Springer and EBSCOhost databases were used, and the keywords were defined:

- *Placement of automated enforcement equipment;*
- *Evasive flow capturing problem;*
- *Enforcement equipments on Highway;*

(location OR placement) AND (equipment OR station OR wim OR enforcement) AND (highways OR roads OR motorway OR carriageway OR freeway).

After this search, information was extracted from the results found, such as title, authors, DOI code, download URL, abstract and publication date. Subsequently, the selection of surveys was carried out through filtering steps. The first was the removal of duplicates, which considerably reduced the number of those considered relevant. After that, the titles were read, a survey was carried out regarding the number of citations and those published before 2019 with less than 5 citations were discarded. Then, the abstracts were read and only those that really coincided with the theme and with the complete content available were kept. **Table 1** shows the number of studies resulting from each selection stage of the systematic review.

Tab. 1 - Quantitative results obtained in the study selection stages of the systematic review

Step	No. of resulting studies
Search in databases	7160
Deletion of duplicate titles	5987
Filtering by relevant titles	241
Sort by number of citations and year of publication	171
Filtering by Relevant Summaries	55
Checking the availability of full texts	54

Source: The authors

Therefore, a complete reading of the selected works was carried out, observing the methods used, the topics addressed and the results obtained. So, 25% of the searches corresponded to the desired theme, presented in **chart 1.**

Tab. 1 - Methodologies used in the studies found in the systematic review.

Reference	Subject addressed	Methodology used
[19]	Weight Inspection	Analytical Hierarchical Process

Reference	Subject addressed	Methodology used
[14]	Weight Inspection	Analytical Hierarchical Process
[11]	Weight Inspection	Two-level optimization model and Branch and Cut algorithm
[20]	Flow Count	Genetic algorithm with biased random keys
[21]	Flow Count	Branch and Cut algorithm and clustering heuristics
[12]	Weight Inspection	Two-level optimization model and Karush-Kuhn-Tucker algorithm
[22]	Flow Count	Selective Weighted Bayesian Model
[23]	Weight Inspection	Analytical Hierarchical Process
[24]	Flow Count	Meta-heuristic bee colony
[25]	Gas emission inspection	Nonlinear programming model and genetic algorithm
[26]	Weight Inspection	Simplified deterministic flow interception model
[27]	Flow Count	Doubly stochastic and conditionally binomial model
[28]	Location of police patrols	Mixed integer linear programming model and heuristic algorithm
[29]	Weight Inspection	Two-level optimization model and heuristics
[30]	Flow Count	Hybrid prediction model with genetic algorithm
[31]	Weight Inspection	Heuristic approach based on greedy algorithm
[10]	Weight Inspection	Two-level optimization model and Lagrangian heuristic
[32]	Weight Inspection	Two-level optimization model and algorithm based on Lagrangian relaxation
[33]	Speed Inspection	Heuristic approach based on greedy algorithm
[34]	Traffic information	Traffic tool implementation
[18]	Weight Inspection	Descriptive statistics of existing station data
[35]	Weight Inspection	Lagrangian heuristic algorithm
[36]	Flow Count	Ant colony metaheuristics and Pareto solutions
[37]	Flow Count	Progressive hybrid algorithm with ensemble coverage structure
[38]	Flow Count	Discrete linear stochastic system

Source: The authors

Among the studies selected for analysis, greater emphasis was given to those that dealt specifically with models for optimizing the location of weight inspection equipment, due to the fact that they considered the evasive tendency of drivers. According to research carried out in Poland regarding these systems, one of the main obstacles faced is evasion by drivers who wish to avoid surveillance. This is mainly due to the fact that the installation locations are permanent, which allows travelers to memorize them, who tend to opt for alternative routes [18].

Among these studies, the model by Marković et al. [10], by the mathematical formulation of the EFCP. In this research, deterministic and stochastic versions of the EFCP were formulated and a two-level optimization model was proposed. The two-level optimization model is an application of game theory [39], which places the equations referring to the "leaders", decision makers, on the first level, and the equations referring to the behavior of the "followers", drivers, in relation to the decisions taken by the "leaders", on the second level. In this article, the two-level model was reduced to only one level, through the premise that both the leader and the followers have the objective of minimizing the distance traveled by vehicles in an illegal situation. With such a reduction, the solution was obtained through a Lagrangian heuristic.

Another research, which uses the two-level optimization model as a way to solve the EFCP, proposes an approach based on Karush-Kuhn-Tucker conditions [12]. The authors claim that there is a maximum distance that drivers are willing to travel to evade inspection, which depends on the profit from the practice of overloading and the cost of the detour performed. Diverging from this theory, another study [29] assumes that there is no limit to the distance covered in order to evade. Therefore, the model proposed here is independent of the shortest paths, using a formulation based on links where the decision variables are associated.

Corroborating this conception, a study was found that uses the two-level optimization model with a pessimistic scenario, assuming that drivers can choose the longest and most expensive paths in order to evade inspection. [11] The proposed model is solved using a cutting plane algorithm and the authors claim that pessimistic formulations can avoid a greater amount of damage to the road network than those that consider a limitation of the path taken.

Therefore, there are several studies regarding the location of weight inspection that use the two-level optimization model, however, each with its own peculiarity. In the case of Arslan et al. [14], prior knowledge of the road network is not necessary to create the model, and possible paths are checked during the solution, as location alternatives are developed. This allows instances of different sizes to be optimized.

As a result of the systematic review, studies on the location of weight control that do not use the two-level model were also found. [19, 23, 26, 35] Some of them [19, 23] propose analytical hierarchical processes to determine a weight for each rural road, with its associated attributes, such as: geology, climate, terrain conditions, available infrastructure, construction and demolition costs and degree of road overload. [23] In case of [35], a Lagrangian heuristic algorithm is proposed, combined with a p-median problem, while [26] proposes a simplified deterministic flow interception model to solve the problem.

In addition to weight monitoring location methodologies, studies were also found regarding the allocation of other types of inspection, as is the case of [28], which addresses the problem of maximum patrol routing coverage, which aims to maximize policing coverage through the placement of police patrols. Using a mixed integer linear programming model and a heuristic algorithm, the conclusion obtained was that there is an increase in policing efficiency when routing has different starting points, not just a base of operations.

Another enforcement device relevant to road safety is the speeding detector. A study on the subject [33] uses a mathematical approach in order to distribute this equipment, finding the ideal number of portable sensors for the best possible coverage of the road network. Different from the speed measurement, a survey was found regarding the distribution of places for inspection of gas emission levels in vehicles. For this, a non-linear mathematical programming model was used, solved by a genetic algorithm, which takes into account the number of inspection agents available and the number of vacancies made available for the inspected vehicles. [25]

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Another type of equipment of great importance on highways is the flow counting sensor, which is intended to characterize road traffic, providing valuable information for road infrastructure planning. In this sense, the studies presented in [20, 21, 22, 24, 27, 30, 36, 37 e 38] address the location of these devices.

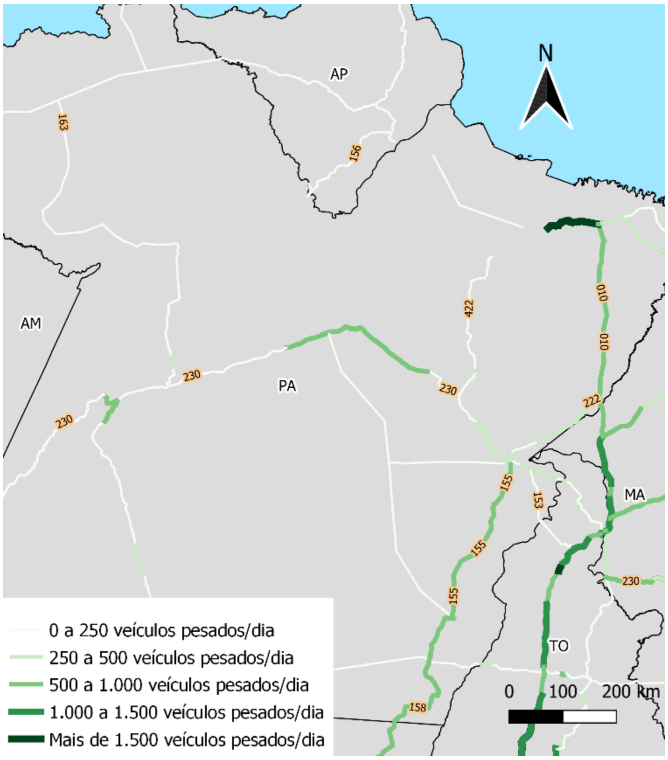
In addition to the location of road equipment through optimization models, there is a research that used GIS (Geographic Information System) to develop a road information system in India [34]. The objective of the study was to prepare a map with all the traffic information and road infrastructure, in order to assist in the allocation of resources for the development of the state.

Considering the multicriteria localization models [19, 23] and the system that uses geographic information [34], the methodology of the Feasibility of Weight Inspection Index (IVFP - Índice de Viabilidade de Fiscalização de Peso) stands out [40], used in Brazil, which was not the result of the systematic review process, but combines both concepts. The IVFP consists of a unified index that aggregates several variables, such as the volume of heavy vehicles, proximity to urban areas, pavement conditions, presence of logistics corridors, among others. This index allows for the comparison between different road sections, in order to support the decision-making process of the most suitable locations for the implementation of weighing stations.

3. Case study: application of models in the road network of the state of Pará

Based on the results obtained through the systematic review, it was decided to implement the models proposed in Marković et al. [10] and Arslan et al. [14], with some adaptations for application in the road network of the state of Pará. The choice of mesh for the study is due to the lower complexity of its composition, which allows greater flexibility in the implementation of optimization methods. **Figure 1** shows the map of Pará, with road sections classified according to the volume of heavy vehicles, according to data from the National Traffic Counting Program (PNCT - Programa Nacional de Contagem de Tráfego), from the National Department of Transport Infrastructure (DNIT - Departamento Nacional de Infraestrutura de Transportes). [41]

Fig. 1 - Map of the state of Pará highlighting the sections with the highest volume of heavy vehicles.

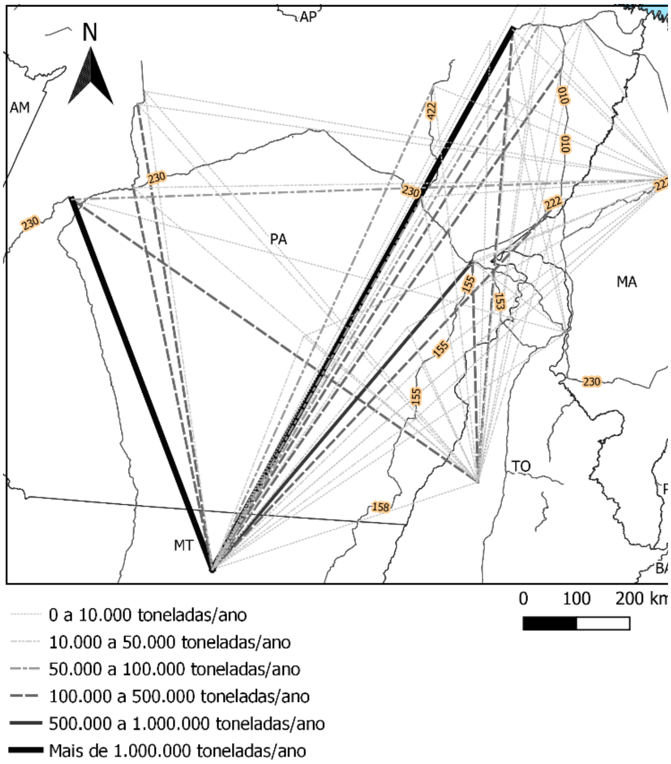


Source: [41] **modified by the authors.**

Observing **figure 1,** it can be seen that the largest volumes of heavy vehicles are concentrated in the eastern region of the state. There are also other volumes in the most central part of the map, but with characteristics of local flows, due to the fact that they do not have continuity along the highway.

Figure 2 illustrates the main cargo flows in the state, according to origin-destination matrix (OD) data published by EPL in 2016, projected for 2020. [42]

Fig. 2 - Map of the state of Pará highlighting the most significant cargo flows.



Source: [42] **modified by the authors.**

Based on **figure 2**, it is believed that most flows come from the states of Maranhão, Tocantins and Mato Grosso, bound for the port of Belém, and also the other way around, from the port of Belém towards these states.

The choice of models [10] and [14] for implementation in the present case study was due to the fact that they consider the evasive behavior of transporters, the first proposed the EFCP and the second capable of solving the problem exactly without the need to previously calculate the routes for the analyzed road network.

After carrying out the study and understanding the models, they were implemented in Python and other restrictions were inserted in them, adapting them to the reality of Brazilian highways. The custom restrictions implemented were:

- Possibility of optimizing the location of new weighing stations, considering that similar systems already exist in the road network, or fixing already selected locations;
- Impossibility of allocating posts in invalid arcs, that is, disregarding in the optimization process road sections that cannot have inspection posts;
- Possibility of using the same weighing equipment in both directions of the highway. This restriction can be used in cases of analyzes on single-lane highways, for example, where it would be economically unfeasible to install inspection equipment in just one direction.

In expressions (1) to (6) the objective function and the restrictions of the first reference model are explained [10]. Expressions (7) to (9) and (16) to (18) contain the custom constraints inserted into the models. It is noteworthy that, for the first model, the shortest paths between the mesh flows were calculated by applying the Dijkstra algorithm, as well as the one performed in the reference study [10].

$$\sum_{(i,j)\in A} x_{ij} w_{ij} + \sum_{f\in F} \sum_{p\in P_f} z_f^p c_f^p \tag{1}$$

s.a.

$$\sum_{(i,j)\in A_f^p} x_{ij} \geq y_f^p \qquad \forall f \in F, p \in P_f \tag{2}$$

$$z_f^p \leq 1 - y_f^p \qquad \forall f \in F, p \in P_f \tag{3}$$

$$\sum_{(i,j)\in A_f^p} x_{ij} \leq |A_f^p| . y_f^p \qquad \forall f \in F, p \in P_f \tag{4}$$

$$y_f \leq y_f^p \qquad \forall f \in F, p \in P_f \tag{5}$$

$$\sum_{p\in P_f} z_f^p \geq 1 - y_f^p \qquad \forall f \in F \tag{6}$$

$$x_{ij} = 1 \qquad \forall (i,j) \in A^D \qquad (7)$$

$$x_{ij} = 0 \qquad \forall (i,j) \in A^I \qquad (8)$$

$$x_{ij} = x_{ji} \qquad \forall (i,j) \in A^S \qquad (9)$$

Where:

A – Set of arcs defined by the source (i) and destination (j);

A^D – Set of arcs (i,j) predefined for the existence of weight inspection;

A^I – Set of arcs (i,j) considered invalid for the allocation of inspection equipment;

A^S – Set of arcs (i,j) in which weighing can be carried out in both directions of the track with a single system;

A_f^p – Set of arcs (i,j) along the way $p \in P_f$ of the flow $f \in F$;

c_f^p – Cost of damage associated with unsupervised flow f that travels along path p;

F – Set of flows f, defined by source and destination nodes and flow volume;

P_f – Set of possible paths p through the mesh for a given flow f;

w_{ij} – Cost of implementing a checkpoint on the arch (i,j);

x_{ij} – Binary variable that takes the value 1 when there is a checkpoint on the arc (i,j) and 0 otherwise;

y_f^p – Binary variable that takes the value 1 when there is at least one checkpoint along the path $p \in P_f$ of the flow $f \in F$ and 0 otherwise;

y_f – Binary variable that takes the value 1 when there is at least one checkpoint along all $p \in P_f$ and 0 otherwise;

Z_f^p – Binary variable that takes the value 1 if the travel flow is not intercepted along the path $p \in P_f$ of the flow $f \in F$ and 0 otherwise.

In **equation 1**, objective function, there is a minimization of the cost of implementing heavy checkpoints and the excessive damage caused by overweight vehicles. In **equations 2, 3 and 4,** the first restrictions are found, which arbitrate: whenever there is at least one sensor in an arc of the road network, ($x_{ij} \geq 1$) along a flow ($y_f^p=1$), the flow will be considered captured ($z_f^p=0$). The fourth constraint, **equation 5**, imposes that y_f swill only assume a value of 1 if all the paths of a flow are covered by at least one weighing sensor. In **equation 6**, the last restriction, only the non-intercepted travel flows are selected ($z_f^p=1$), in order to use them in the calculation of the variable of excessive pavement damage.

Regarding custom restrictions, **equation** (7), coinciding with **expression (16)**, arbiter than the variable x_{ij} will assume value 1, if the arc (i,j) is contained in the set of pre-defined inspection arcs. **Expressions (8) and (17)** will be equal to zero if the arc (i,j) is contained in the set of invalid arcs, in which it is not possible to position surveillance systems. **Expressions (9) and (18)** determine that xij will take on the same value as xji when the same weighing system needs to cover the highway directions.

Then, the **equations** of the second reference model are found [14]

$$min \sum_{(i,j)\in A} w_{ij}x_{ij} + \sum_{f\in F} \sum_{(i,j)\in A_f} c_f d_{ij} r_{ij}^f \qquad (10)$$

s.a.

$$1 - \sum_{(i,j)\epsilon A^p} x_{ij} \leq u_f \qquad f \in F, p \epsilon P_f \qquad (11)$$

$$\sum_{(i,j)\in A_f} r_{ij}^f - \sum_{(j,i)\in A_f} r_{ji}^f \begin{cases} = \{u_f & se\ i \\ = s_f - u_f & se\ i \\ = t_f & 0\ caso\ contrá \end{cases} \qquad (12)$$

$$f \in F, i \epsilon N_f$$

$$r_{ij}^f \leq 1 - x_{ij} \qquad f \in F, (i,j) \in A_f \qquad (13)$$

$$u_f, r_{ij}^f \geq 0 \qquad f \in F, (i,j) \in A_f \qquad (14)$$

$$x_{ij} \in \{0,1\} \qquad (i,j) \in A \qquad (15)$$

$$x_{ij} = 1 \qquad \forall\,(i,j) \in A^D \qquad (16)$$

$$x_{ij} = 0 \qquad \forall\,(i,j) \in A^I \qquad (17)$$

$$x_{ij} = x_{ji} \qquad \forall\,(i,j) \in A^S \qquad (18)$$

Where:

A_f – Set of arcs of the shortest possible path for the flow f;

A^D – Set of arcs (i,j) ppre-defined for the existence of weight inspection;

A^I – Set of arcs (i,j) considered invalid for the allocation of inspection equipment;

A^S – Set of arcs (i,j) in which weighing can be carried out in both directions of the track with a single system;

c_f – Unit damage caused by flux $f \in F$;

d_{ij} – Arc length (i,j) ∈ A;

N_f – Set of nodes that make up the shortest possible path for the flow $f \in F$;

r^f_{ij} – Binary variable that takes the value 1 if the arc (i,j) ∈ A s traversed by the flow f ∈ F; and 0 otherwise;

S_f – Flow source node $f \in F$;

t_f – Flow destination node $f \in F$;

u_f – Binary variable that takes the value 1 if the travel flow is not intercepted along the flow $f \in F$ and 0 otherwise;

x_{ij} – VBinary variable that takes the value 1 when there is a checkpoint on the grid arc and 0 otherwise;

w_{ij} – Cost of installing a checkpoint on the arch (i,j).

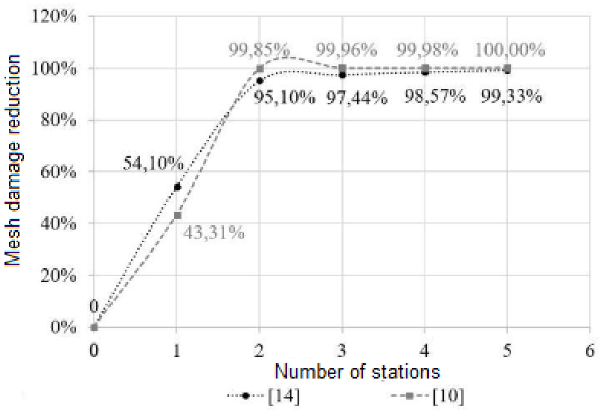
The model has as an objective function (Equation 10) the minimization of damage to the infrastructure, caused by the practice of overweight not intercepted, but also the minimization of costs with the installation of weighing sensors. Regarding restrictions, the one represented in **equation 11** maintains the variable u_f binary, assuming the value 1 if the flow is not intercepted, that is, if any of the paths between the source and destination nodes of the flow does not have inspection (x_{ij}=0). **Equation 12** defines the continuity of the flows, ensuring that the paths through the mesh are composed of arcs in sequence, starting from the origin to the destination of each flow. **Equation 13**, on the other hand, restricts the selection only to the arcs traversed by the flows under analysis, while **equation 14** is a restriction of non-negativity of the variables u_f and r^f_{ij}. **Equation 15** represents the domain of the variable x_{ij} and, finally, **expressions (16) to (18)**, custom restrictions, were mentioned earlier.

This model, [14], is accompanied by a branch-and-cut algorithm, with the generation of customized constraints throughout the solution. The custom constraints, with the equations proposed in the article, guarantee that the possible paths for the evasive flows will be verified, calculating these paths during the generation of alternative solutions for the problem. The branch-and-cut algorithm is the branch-and-bound algorithm associated with cutting planes, which branch the problem. Therefore, the objective function is divided into smaller subproblems, called "tree nodes" and at each node, cuts are generated, making the subproblems generate better dual limits. After completing the computational implementation of the model, the road network in the state of Pará was analyzed. It should be noted that the tolerance considered for the paths taken by the carriers was 20%, that is, it was admitted that no deviations greater than 1.2 times the shortest path between the OD pairs will be made.

As a model analysis parameter, the percentage of damage reduction in the road network was chosen. It is known that the practice of being overweight causes damage to the infrastructure, so it is aimed that these damages are reduced as much as possible. To calculate the damage caused by overloaded vehicles, the estimated volume was multiplied by the distance traveled for each of the traffic flows in the state network. The calculation is carried out in a specific way for captured and non-captured flows, when inspection posts are installed. Thus, it was possible to identify the percentage of damage reduction by placing the sensors.

In **figure 3**, there is a graph that indicates the percentage of damage reduction achieved with the addition of checkpoints, for the two implemented models.

Fig. 3 - Grid damage reduction percentage graph according to the number of weigh stations allocated in the Pará grid.



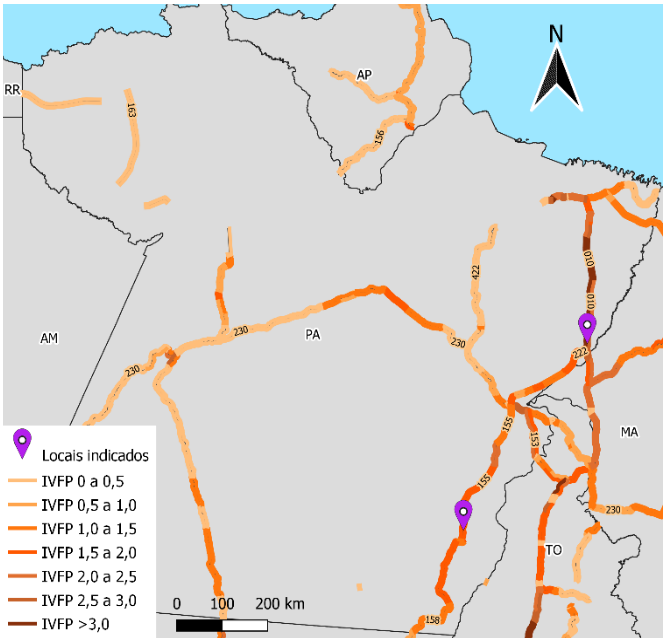
Source: The authors.

Observing **figure 3**, it is noticed that the results of the two tested models are very similar, which suggests that both are effective for the optimization of inspection. However, the model [14] has a lower computational cost, due to the fact that it does not require the previous generation of the routes of the considered flows.

Another pertinent observation is the optimal number of stations for monitoring the road network. It can be seen that, for the analyzed case, two stations would be ideal, as this way a large damage reduction is obtained, greater than 95% in both optimization models. By allocating a higher amount, the benefit in terms of reducing the cost of overweight is smaller, not offsetting the costs of implementing equipment. It should be noted that the road network in the state of Pará is not very complex, requiring a small number of weighing stations to obtain good coverage.

Based on these considerations, it was decided to allocate two weight inspection posts in the study site, shown in **figure 4.**

Fig. 4 - Map of the state of Pará, highlighting the stretches with the highest IVFP and the locations indicated for receiving weighing stations.



Source: The authors

It is noteworthy that the stretches with the highest value of IVFP [40] have greater relevance for weight control. Even though the IVFP does not consider the possible escape routes, it can be seen in **figure 4** that the locations indicated through the application of the optimization models are found in places with high IVFP, which suggests that this methodology, allied with optimization models that consider evasion, they are consistent tools for planning weight inspection infrastructure.

Observing the characterization of the state's traffic - location of heavy vehicle volumes **figure 1** and location of cargo flows **figure 2** - it can be seen that the suggested stations are located in places with the highest density of heavy vehicles in the state, which indicates the coherence of the optimization models in locating the main points for installation of inspection equipment.

4. Conclusion

The general objective of this work was the application of optimization models for the location of weight inspection equipment. For this, a case study was carried out in the road network of the state of Pará, from which it was concluded that with few sensors, placed in strategic and optimized locations, a satisfactory reduction in the damage caused by overweight vehicles to the infrastructure can be obtained.

In addition, it should be noted that the systematic review carried out fulfilled the proposed objective, which was to highlight the main models for locating inspection equipment used nationally and internationally. In this review, studies were located on the installation of sensors for flow counting, weight control, speed and vehicle emissions, among others, with different resolution methodologies for the proposed problems.

In addition, it is observed that the IVFP methodology, combined with optimization models that consider the evasive tendency of carriers, may represent an interesting alternative to aid in decision-making in relation to the allocation of traffic inspection posts.

Considering that the evasive practice of drivers is a relevant reality, it is noted that it is necessary to take this fact into account when the allocated equipment is intended for inspection. This consideration, still in the planning phase, will not increase installation costs, but rather optimize the locations chosen for installing the devices, which will minimize the occurrence of short deviations, which facilitate the escape of violators.

Finally, considering the negative impact caused by the evasive tendency of illegal drivers in several aspects, it is believed that it is pertinent to create networks of monitoring points that take into account the reality of Brazilian highways and the evasive tendency, in order to assist transport infrastructure managers in decision-making and increase the effectiveness of traffic enforcement.

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