ESCUELA POLITÉCNICA DE INGENIERÍA DE GIJÓN.

MÁSTER UNIVERSITARIO EN INGENIERIA INDUSTRIAL

OPTIMIZING LOGISTICS NEWTORKS

D. HERRERO BELLO, Pelayo
TUTOR:Dr. PETRI HELO

2016

Abstracto

La adición de nuevos almacenes a los ya existentes en la red de logística de una empresa es un problema que es difícil de evaluar ya que requiere una gran cantidad de datos diferentes para analizar y pertenece a las decisiones estratégicas en la gestión logística. En este trabajo, se realizó el planteamiento de cómo calcular el número óptimo de almacenes y establecer la ubicación de la nueva los necesitan para lograr el rendimiento óptimo de las redes de logística. Para determinar la ubicación óptima, el estudio de la actividad actual y costo de las redes de logística de la empresa fue hecho. Para obtener estos datos, el modelado y programación de la manera actual de proceder de la red de logística fue hecho y resuelto más tarde por el uso de un software. El costo de la carga generalmente es difícil de calcular para las empresas de transporte, en este trabajo, se llevaron a cabo diferentes enfoques para estimar el costo total de la tarea de carga. Además, todos los enfoques se estudiaron y analizaron sus resultados e influencian en el rendimiento de las redes de logística para ver las claves que más influencian en el rendimiento al afectar al costo total, como la tasa de utilización o variación de costos de combustible. Los criterios diferentes cuando se refiere a la asignación de los pedidos a las empresas de transporte es la principal causa del salario desequilibrado al final del ejercicio económico, y esto puede llevar a problemas entre el personal. La asignación justa de las órdenes de entrada para las empresas de transporte donde al final del ejercicio todas las empresas de transporte tendrán similares salarios va a ser propuesto. Finalmente, modelos complementarios que incluyen otras variables y criterios como inventario o disponibilidad y la ubicación de las empresas de transporte van a ser propuestos como posibles futuras investigaciones con el fin de lograr la optimización total de la red logística.

Resumen

Las mejores ubicaciones de los puntos de recogida posible es una cuestión que determina el rendimiento de las redes de logística global. Generalmente, las ubicaciones de nuevos depósitos forman parte de las decisiones estratégicas, ya que están hechas para un período de largo plazo de tiempo por su dificultad inherente en el caso de necesitar un cambio en la ubicación, puesto que se requeriría la construcción de la nueva nave al mismo tiempo que la localización previa sigue funcionando para ser capaz de proporcionar cualquier servicio que la empresa ofrezca. Esta situación dará lugar a un procedimiento de operación muy costoso, por lo que es muy importante evitar ese tipo de situaciones. Es por ello que las decisiones estratégicas, y especialmente aquellas con respecto a la ubicación de almacenes, debe hacerse cuidadosamente y a través de diferentes estudios con el fin de obtener la mejor ubicación que lograría la mejor reducción en términos de costo. Para realizar los estudios en cuanto a la mejor ubicación, se requiere una cantidad importante de datos, especialmente la demanda a través de los últimos años, para ser capaces de diferenciar entre otras cuestiones que puedan afectar la ubicación las decisiones, como la estacionalidad o tendencia en la demanda.

La capacidad de los almacenes es una variable importante que generalmente determina la ubicación de los almacenes. Si se necesita una gran capacidad, por un lado, el costo de construcción y costo de mantenimiento de las naves van a ser importantes, y también el costo de inventarios sería un factor relevante. Por otro lado, el costo de transporte disminuiría ya que sería posible llevar carga completa de contenedores, lo que disminuirá el costo. Otros factores como el aumento del precio del combustible, pueden afectar las decisiones de colocación de un nuevo

almacén puesto que afectan a las redes de logística global. Idealmente, una rede de logística equilibrada es aquella que no se ve afectada fuertemente por los factores de riesgo, tales como las variaciones de precio de combustibles por ejemplo. Mediante la adición de nuevos almacenes a la estructura logística existente, es posible ver su influencia observando la respuesta en los costos cuando hay cambios realizados por los factores de riesgo.

Para estudiar la mejor ubicación de los almacenes, es importante conocer el rendimiento de cada localización individual, por lo que sobre cada lugar se podrían tomar decisiones con datos objetivos que el gerente de la empresa podría usar como indicadores clave de rendimiento, como, por ejemplo, el costo asociado por orden en cada ubicación, el volumen de material procesado por ciertos lugares, etc.

Sin embargo, hay algunas situaciones donde esta información no está disponible porque la empresa no ha desempeñado la actividad durante mucho tiempo o porque carecen de un sistema de tecnología de información adecuada que se encargue del almacenamiento y procesamiento de los datos, puesto que generalmente estos sistemas son bastante caros y requiere gran inversión en gestión de la información. Otro escenario posible podría ser cuando una compañía planea ejecutar sus actividades en otro país y sólo tienen una pequeña cantidad de datos disponibles basados en pronósticos. En cualquiera de los casos, los datos de la actuación podrían obtenerse mediante el modelado del problema y más tarde con el uso de un software, ejecutar una simulación que encontrara cual es la mejor ubicación para cada orden y así optimiza el rendimiento general.

La asignación óptima de los pedidos a las mejores ubicaciones depende de muchos factores como los costos reales que influyen en el costo de los transportes o las diferentes formas de procedimiento. Idealmente, un buen indicador del rendimiento de cada ubicación, que determinaría si el lugar está bien situado, es la existencia de zonas superpuestas entre las zonas de influencia de cada ubicación. Si estas áreas superpuestas son frecuentes y numerosas, esto significa que el rendimiento de la red logística global es bastante pobre y así hay espacio para mejora del rendimiento.

También es posible, gracias a la simulación del problema modelado, ver que cambios conducirían a disminuir las áreas de superposición o qué factores son los que tienen más influencia en esta cuestión. Una vez que se identifica el desempeño general e individual que juega cada figura en las redes de logística, decisiones tales como cambios de ubicación de los almacenes, construcción de almacenes adicionales, establece la capacidad de los tráileres en más o menos volumen, etc., podrían realizarse, por lo que la importancia de tener un buen modelo matemático que describe con precisión el rendimiento de la empresa es una cuestión clave.

Una vez que la información referente a las asignaciones de órdenes para la mejor ubicación está disponible, en este caso, obtenido por la simulación, las órdenes deben ser asignadas a las empresas de transporte. La compañía distribuye los pedidos entrantes a las empresas de transporte disponibles. Los criterios diferentes cuando se refiere a la asignación de las órdenes al conjunto de empresas de transporte es la principal causa del salario desequilibrada al final del término, y esto puede resultar en problemas entre la plantilla de transporte de las diferentes empresas, por lo que se aprecia la importancia de tener un buen criterio a la hora de referirse a la distribución de los pedidos entrantes entre las empresas de transportes diferentes , que serán capaces de dar lugar a pequeñas diferencias en los ingresos o incluso ninguna diferencia en absoluto.

Como se ha visto por toda la descripción anterior, el funcionamiento de las redes de logística es una continua evaluación de ventajas y desventajas entre muchos factores, así que es difícil encontrar optimización real de todos los factores, y especialmente si se estudiaron individualmente pero no el impacto que tendrían en el rendimiento general. En este trabajo, un estudio exhaustivo de la cuestión del transporte se va a hacer, y más tarde la influencia de otros factores van a ser estudiados para establecer la influencia de cada factor, tanto local como global, en la red logística, con el fin de lograr la optimización total de las redes de logística.

Los puntos de recogida están idealmente situados cerca de las órdenes con el fin de reducir el costo de transporte y también para poder operar dentro de la restricción limitada de la ventana de tiempo. En este caso, un conjunto de datos que consiste en las órdenes de un período de tiempo de dos semanas fue dado para analizar el rendimiento de la red logística. Este conjunto de datos puede ser utilizado como una aproximación de cómo las órdenes se comportan entre todo el año si se supone que hay no hay estacionalidad en la demanda y el conjunto de órdenes es bastante representativo de la distribución de pedidos en todo el año, y ayudará a determinar el rendimiento de las redes de logísticas para descubrir posibles puntos de optimización. La ubicación de las ordenes viene en forma de coordenadas y que van a ser convierte en distancia mediante el uso de una fórmula y corregido más adelante a la distancia real de conducción, puesto que generalmente no es la misma que la distancia geográfica ya que depende del estado de las carreteras o la geografía de la zona. Por el uso de un factor, llamado en este problema el factor de contorno, se reflejará la verdadera distancia.

Es fundamental señalar que todos los pedidos que se llevan a primero a los puntos de recogida, posteriormente deben llevarse a una de las fábricas. Estos recursos se llevan desde los puntos de recogida a las fábricas, y, puesto que no hay ningún requisito de tiempo una vez que se recogen de las granjas, podrían ser enviados a la fábrica por diferentes procedimientos operativos. Por un lado, es posible esperar a que un trailer esté completo antes de enviar toda la carga de los recursos a la fábrica, con el fin de lograr una reducción de los costos mediante la optimización de la tasa de utilización de la capacidad del remolque. Esta manera de proceder es también conocida como peso completo o FTL.

Como se dijo anteriormente, el rendimiento de cada ubicación va a ser estudiado a través de los resultados obtenidos de la simulación. Los resultados de esta simulación van a utilizarse para evaluar el desempeño estimado de la red global de logística. Esto va a hacerse observando la existencia de superposición de áreas y el rendimiento individual de cada ubicación. Además, el rendimiento global va a ser analizado, tanto de forma general como individual, de cada lugar, agregando un nuevo punto de recogida para ver la influencia que tendría mirando el costo total y también las áreas superpuestas. Otros factores, como la capacidad de los remolques o variación del costo del combustible van a ser estudiados también para ver el impacto que tendría en el rendimiento general, ya que esto puede afectar también la decisión estratégica final de añadir un nuevo punto de recogida dependiendo del efecto que tienen sobre los costos totales de logística.

Además del problema de localización, otra cuestión es la distribución de los pedidos dentro de las empresas de transporte.

La empresa asigna una a una de las diez empresas de transporte privado que trabajan con la empresa cliente. Para el problema de asignaciones justas, se supone que las empresas son responsables de todos los pedidos desde el principio hasta el final. Además, se supone también que todas las empresas de transporte están en posesión de al menos un trailer y un camión, y son responsables para el transporte de los pedidos que se tomaron en los puntos de recogida a la fábrica por el trailer, por lo que son capaces de hacer ambos tipos de transporte. Además, puesto que no se conoce la ubicación de las empresas de transporte, también se supone que todas las empresas son capaces de hacer cualquier orden, independientemente de la ubicación. Relacionados con el tema de los lugares desconocidos de las empresas de transporte, es importante remarcar que, en este problema, la distancia de ir desde su ubicación inicial a las granjas por el camión y que van desde las fábricas hasta su casa por el trailer, no va a tomar en cuenta ya que la ubicación inicial y final de los conductores de las empresas afectarán ampliamente a los resultados finales.

En este problema, las diversas localizaciones de las órdenes, los puntos de recogida y fábricas se dan en términos de latitud y longitud. Para hacer los cálculos más fáciles para que el software utilizado para la simulación, estas coordenadas fueron convertidos en kilómetros siguiendo el siguiente procedimiento basado en la fórmula de Haversine:

La fórmula del Haversine es una ecuación que permite para calcular la distancia en kilómetros entre dos puntos de sus longitudes y latitudes.

Como al calcular la distancia entre dos puntos, por el uso de la fórmula del Haversine, no siempre es la distancia real de viaje porque la distancia real tiene una ruta diferente y caminos que la distancia recta y la importancia de la geografía diferente de ciertas áreas, por lo que se debe aplicar un factor de corrección para este problema. El factor se denomina factor de contorno y es el cociente entre la distancia de dos puntos y la distancia real que se necesita para cubrir por carretera.

Después de una cuidadosa revisión de la literatura, es posible concluir que una solución para este caso particular, en el que primero algunos recursos necesitan recogerse para alcanzar los requisitos de tiempo, y más tarde estos recursos se envían a la fábrica si primero se recogieron en los puntos de recogida, no se encuentra.

Algunas asunciones fueron hechas para encontrar una solución para el problema:

-Cada orden debe ser procesada individualmente de la granja a los puntos de recogida o las fábricas.

La razón por qué se hizo este supuesto es porque no hay información de cuando se hicieron los pedidos, así que, para mantener la restricción de la ventana de tiempo de 3 días, se supone que las órdenes son procesadas individualmente por un conductor y no es posible llevar más de una orden al mismo tiempo por el mismo conductor. Una vez que existan suficientes datos disponibles, podría introducirse un dumping factor para reducir al mínimo el impacto del transporte que podría representar una aproximación más realista.

-No hay ningún inventario, capacidad o demanda en los almacenes.

La razón de este enfoque es la falta de información de las tasas de consumo de fábricas de los productos, la capacidad de las fábricas o los puntos de recogida y por lo tanto, el inventario. Como el tiempo de entrega para ese problema es muy pequeño, el costo de inventario de seguridad no será muy relevante, pero la explotación coste de ciclo de inventario, en caso de que el número estaba disponible, tendría una influencia muy fuerte en el modelo

Para este problema, la notación siguiente se introduce para formular el modelo matemático:

I = {1} conjunto de órdenes

J = {1..m} conjunto de sitios de ubicación

Fj: costo configurar sitio de ubicación $j \in J$;

Di, j: distancia entre orden i y de ubicación j

LJ: Distancia ubicación j fábrica 1

CS: Costo por kilómetro (en euros) para el camión

CB: Costo por kilómetro (en euros) para el trailer

CLS: Costo por carga (en euros) para el camión

CLB: Costo por carga (en euros) para el trailer

Cap: Capacidad del trailer

Wi, j: peso de orden i a j (punto o centro de colección)

a: mínimo de instalaciones abiertas

b: numero de instalaciones abiertas

Variables de decisión

Dado el tamaño del conjunto (n = 1656 órdenes, m = 6 fábricas) el número de variables en este modelo supera el límite de los softwares tradicionales . Por esta razón, el problema va a ser modelados y resueltos usando un software de optimización.

Las variables de decisión en este problema son:

XI, j: variable binaria que toma el valor de 1 si la orden se asigna a ubicación j y 0 si no

YJ: Variable binaria que toma el valor de 1 si se abre la localización j y 0 en caso contrario.

Función objetivo

Una vez que la notación y las variables utilizadas fueron descritas, la función objetivo del modelo consiste en la siguiente:

$$\min[\sum_{j}^{J} Fj * yj + \sum_{i}^{I}\sum_{j}^{J}(Dij * Xij * Cs + Xij * Cls) + \sum_{i}^{I}\sum_{j}^{J}(\frac{(Wij * Xij)}{Cap} * Lj * Cb + \frac{(Wij * Xij)}{Cap} * Clb)]$$

s.t.

$$\sum_{j}^{J} Xi,j = 1,\ \forall i \in I$$

$$Xi,j \in \{0,1\}, \qquad \forall i \in I, \forall j \in J$$

$$Yj \in \{0,1\}, \qquad \forall j \in J$$

$$a \leq \sum_{j}^{J} Yj \leq b, \qquad \forall j \in J$$

$$Xi,j \leq Yj,\ \forall i \in I, \forall j \in J$$

El software utilizado para este problema fue GLPK versión 4.0.

Adición de un nuevo punto de recogida

Los métodos utilizados para establecer la ubicación de un punto de recogida adicional van a explicarse. En este problema se utilizaron dos métodos principales, el método centro de gravedad y el método de Weber.

Método de centro de gravedad

El modelo de centro de gravedad se basa en el cálculo de las coordenadas óptimas del nuevo punto de recogida mediante longitud y latitud ponderadas, donde el peso utilizado podría ser diferentes factores.

Método de Weber

Con el método de Weber, el principal objetivo es determinar las coordenadas que minimizan la distancia ponderada. Los pesos están calculados por diferentes factores que podrían utilizarse, así como en el método de centro de gravedad.

Conclusiones

En este trabajo, se hicieron diferentes enfoques para la optimización de las redes de logística.

Se observó que el factor con mayor influencia es el índice de utilización, donde la influencia más grande en términos de porcentaje toma un valor de alrededor 30%. Este resultado llevó a la conclusión de que puede no valer la pena hacer grandes esfuerzos para lograr una gran capacidad, si esto es bastante caro o requiere de mucha inversión. En cambio, diferentes estudios de las actuaciones del modelo con diferentes capacidades, se pueden hacer para elegir la estrategia correcta. Otra ventaja más allá de los costos de tener una capacidad de 30% es un nivel de inventario inferior y así un inventario de más bajo costo. Es importante remarcar que en este problema, no había costos de inventario asociados a los centros de recogida y también no hay problema de capacidad en ellos, pero, en caso de que el costo de mantener el inventario fuera un factor con un valor conocido, el enfoque de FTL habría sido mucho más caro ya que el inventario en los puntos de recogida debe ser mucho más alto y así, ofrecerían peores resultados en términos de costos que usando el 30% de la tasa de utilización.

Para futuras investigaciones, se podría calcular el costo total de inventario mediante el establecimiento de un valor de costo de holding del inventario y posteriormente los costos relacionados con ciclo y seguridad para cada lugar. Esto conducirá a resultados diferentes, pero más cercanos a la optimización total.

Otras investigaciones futuras relacionadas con el inventario y la capacidad, podría ser establecer una política de inventario de reposición de una revisión continua. Para hacer esto, las tasas de consumo de los recursos de las fábricas deben ser estimadas primero y luego, teniendo en cuenta los recursos que están en las fábricas para producir el producto final y la tasa de consumo, la frecuencia con la que cada tráiler se envía a las fábricas variaría dependiendo de los recursos disponibles en la fábrica y no sólo cuando el tráiler esté completo.

Es notable advertir la importancia de establecer un costo exacto por carga. Para establecer el costo por carga de los diferentes enfoques, se utilizaron diferentes métodos, pero para un mejor análisis del desempeño real, es muy importante establecer el valor exacto del costo por carga para futuras decisiones en cuanto a las redes de logística, y este valor debe ser obtenido por métodos internos de la empresa.

Se estudió la adición de nuevos puntos de recogida a los ya existentes. Como se vio, el mejor rendimiento se logró con un punto de recogida adicional, pero no cuando se agregaron dos nuevos puntos de recogida. Se trata de una decisión estratégica importante que debe tenerse en cuenta debido a los ahorros potenciales que podrían conducir la construcción de un nuevo punto de recogida.

Además, se vio cómo la adición de un punto de recogida puede funcionar como un factor de mitigación de los riesgos en caso de variación de combustible, ya que la variación en el costo total cuando el punto de recogida adicional fue añadido fueron menos que en el modelo sin el adicional. Debido a la gran variabilidad del precio del combustible, esto debe tenerse en cuenta para minimizar los riesgos. Es importante remarcar que la adición de un nuevo punto de recogida también potencia el efecto del aumento de la capacidad, una cuestión que debe tenerse en cuenta al determinar las estrategias de desempeño.

Para la ubicación de los puntos de recogida adicionales, se utilizó el método del centro de gravedad y el método de Weber y se emplearon diferentes factores. Los diferentes resultados cuando diversos factores fueron usados llevan a la conclusión de que, al agregar un nuevo punto de recogida, debe hacerse un estudio profundo ya que las decisiones de localización son muy difíciles de revertir.

Es importante mencionar nuevamente que, en este modelo, debido a la falta de información de las órdenes, se suponía que las órdenes fueron procesadas individualmente por las empresas para poder trabajar bajo el marco legal, que establece que todos los pedidos deben ser recogidos en menos de tres días. En el caso de que la información del tiempo de los pedidos pudiera obtenerse en el futuro, sería posible trabajar en nuevos modelos donde estas cuestiones se tendrían en cuenta, pero sin tratarlos como problemas de enrutamiento de vehículos (VRP), ya que debe sólo tenerse en cuenta como un análisis para el rendimiento de las actuales redes de logística y para estudios de nuevos emplazamientos posibles. Sin embargo, con la información del tiempo de los pedidos entrantes, es posible trabajar en el desarrollo de algunos métodos que toman en cuenta los diferentes criterios de agrupamiento para determinar la agregación de las órdenes. Algunos criterios y limitaciones que podrían seguirse puede ser tiempo, la disponibilidad del conductor y distancia, capacidad del camión, peso de la orden, distancia entre órdenes y distancia entre órdenes. Más tarde, sería posible calcular un "dumping factor" basado en el promedio de órdenes que se agrupan. Con este factor aplicado e implementado en el modelo actual, llevaría a resultados mucho más realistas en términos de rendimiento.

En cuanto a la distribución de los pedidos entrantes dentro de las empresas de transporte, la herramienta desarrollada conducirá a la nueva distribución de los pedidos en la que cada transportista percibirá la misma cantidad de dinero. Es necesario decir que otras consideraciones a la herramienta desarrollada como localización de los transportadores, la disponibilidad de los transportadores, la disponibilidad del camión o el remolque, etc. podrían ser establecides en la herramienta, así asignaría las órdenes para la mejor ubicación teniendo en cuenta todas las consideraciones necesarias.

Con los datos obtenidos de la simulación y el modelo calibrado, pueden hacerse estudios de posibles ubicaciones de los puntos de recogida existentes trasladando a través del método del centro de gravedad. Además, una vez lograda la calibración del modelo, podría también ser utilizado para estudiar la implementación de nuevos puntos de recogida que reduciría el costo total.

La configuración del dumping factor podría seguirse por diferentes criterios como la densidad del área, que es el número de pedidos por zona, el factor de contorno de la zona o la distancia promedio de un área a punto de recogida.

El desarrollo de este modelo y el uso de un programa de simulación, como se ha visto en este trabajo, es una herramienta importante con un gran potencial financiero, ya que los distintos enfoques pueden ahorrar una importante cantidad de dinero gastado en las redes de logística si se implementa la solución óptima. La herramienta es especialmente útil cuando se trata de estudiar diferentes escenarios que podrían ser divididos en dos categorías principales:

-Actualmente realizando actividad de la empresa.

En este escenario, donde hay una gran cantidad de datos disponibles, el uso de la herramienta ayudará a estudiar el impacto total de algunas decisiones como:

-Localización de puntos de recogida en la actualidad: mirando algunos KPI u otros indicadores, como por ejemplo €/ orden en cada punto de recogida, total número de kilogramos que recibió, u otro factor que la empresa podría utilizar, es posible estudiar localmente el rendimiento real de esa ubicación y el impacto que tiene en la red de logística total.

-Capacidad de los tráileres: también es posible ver cómo las decisiones de cambiar la capacidad de modificar el número de contenedores, aumentando o disminuyendo a ellos, el impacto de los costos por carga, etc., que afectan el rendimiento de las redes de logísticas y con ello, tomar algunas decisiones con respecto a este tema.

Compañía planea realizar actividad en otro país

En este escenario, hay menos datos, por lo que no es posible estudiar con precisión el rendimiento de la empresa con la herramienta. Sin embargo, puede ayudar a tomar decisiones como:

-Localización de puntos de recogida posible: basado en la simulación, es posible ver en qué lugares sería mejor colocar los almacenes. Se ha observado en este trabajo que son muchas las estrategias para seleccionar las posibles ubicaciones de los puntos de recogida, así antes de finalmente poner un punto de recogida en algún lugar, es posible ejecutar la simulación para ver el desempeño real con esos lugares, y en caso de que no está bien, la ubicación puede ser cambiada y estudiar otra ubicación sin coste alguno. Esta es una ventaja muy grande que es importante ya que puede ahorrar una cantidad importante de dinero sin inversión necesaria.

-Estrategia de los camiones y trailers a implementar: es posible estudiar cual es la mejor estrategia para lograr la optimización total. Este estudio podría llevarse a cabo cambiando los valores de la capacidad de los camiones y trailers. Las diferentes estrategias que la empresa podría usar, pueden ser simuladas primero y luego analizar los resultados para seleccionar la estrategia para llevar a cabo. También es una herramienta útil en caso de que la empresa desea estudiar cómo las redes de logística total van a reaccionar a los cambios en la demanda y cómo afectará a cada situación local y el rendimiento total de la empresa a nivel global, y si vale la pena cambiar la estrategia en caso de cambios de la demanda con el fin de buscar la mejor respuesta a los cambios.

-Impacto de los diversos factores de riesgo en el rendimiento: es posible analizar cómo la variación de algunos factores, como el precio del combustible, podría afectar el rendimiento total de las redes de logísticas y estudiar posibles soluciones que pueden funcionar como herramientas de mitigación de riesgos para esos riesgos.

Es importante decir que este modelo podría tener algunas limitaciones debido a la diferencia con el rendimiento real en función de la estrategia de la empresa. Para resolver estas diferencias, el modelo debe cambiar y calibrarse cada vez que la diferencia sea notable respecto a los datos obtenidos del rendimiento real, por la adición de diversos factores que corrijan el modelo, y una vez que el funcionamiento del modelo es muy similar al funcionamiento actual de la empresa, entonces podría ser utilizado para el estudio de los factores que se comentaron anteriormente , pero es realista pensar en la implementación de esta herramienta con el fin de estudiar los resultados y evaluar el desempeño de la empresa dependiendo de las categorías que estén actuando, y es muy útil para utilizarlo también como una primera aproximación a cómo la empresa va a comportarse en caso de que los datos no están disponibles o en el caso de un cambio en la estrategia quiera ser estudiada.

TABLE OF CONTENTS

UNIVERSITY OF VAASA
Faculty of Technology
Author: Pelayo Herrero Bello
Topic of the Thesis: Optimizing Logistics Networks
Name of the Supervisor: Petri Helo
Degree: Master of Science in Industrial Engineering
Year of Entering the University: 2016
Year of Completing the Thesis: 2016 **Pages:** 193

ABSTRACT

The addition of new warehouses to the existing's ones in the logistic network of a company is a problem that is hard to evaluate since it requires a big amount of different data to analyse and belongs to strategic decisions in the logistics management. In this work, the approach of how to calculate the optimal number of warehouses and set the location of the new ones needed to achieve the optimal performance of the logistics networks was done. For determine the optimal location, the study of the current performance and cost of the logistics networks of the company was done. For obtain this data, the modelling and programming of the current way of procedure of the logistic network was done and later solved by the use of a software. The cost of load usually is hard to estimate for transport companies, in this work, different approaches for estimating the total cost of the loading task were conducted. In addition, all the approaches were studied and analysed their results and influence on the performance of the logistics networks to see the key factors that most influence the performance by affecting the total cost, like the utilization rate or fuel cost variation. The different criteria followed when it refers to the assignment of the orders to the transports companies is the main cause of the unbalanced salary at the end of the term and this can lead into problems among the staff. The fair allocation of the incoming orders for the transport companies where at the end of the term all the transport companies will have similar salaries going to be proposed. Finally, complementary models which include other variables and criteria like inventory or availability and location of the transport companies are going to be proposed as possible future researches in order to achieve the total optimization of the logistic network.

KEYWORDS: Optimization logistic performance, assignments orders, Optimal locations, GLPK, Logistic modelling.

1. INTRODUCTION

The work done in this project was done for a logistics consulting company where a customer case was presented. The case presented by this customer was the foundations that lead to announce the main problem of this work and also the source of some the data that were used in order to solve the case.

The customer company is a producer of protein feed, rendered fat and fertilisers which is based on Norway. The company main activities are also the waste collection, treatment and disposal activities. The customer company gets some of their primary resources from farms all along Norway, where those resources need to be collected in three days by a regulation established by the law. Because of the small time window, there are some collection points located near to some farms in order to be able to recollect the resources in the time specified in the regulation. In this collection points, all the resources from the farms are collected, and after, send into one of the two factories that the company has in Norway, where the resources are processed to produce the final products. Because of this way of procedure, it can be seen the importance of the location of the collection points as a strategy to be competitive to reduce transport costs and thus, overall logistics cost, which will allow the company to be more competitive if a reduction is achieved through optimization.

The best locations of the possible collection points is an issue that determines the performance of the overall logistics networks. Usually, the location of new warehouses are part of the strategic decisions, since they are made for a long term period of time because its inherent difficulty in case of a change in the location is needed, since it would require the construction of the new warehouse at the same time the old location continues operating for still being able to provide whichever service the company offers. That situation will lead to a really expensive operation procedure, so it is extremely important to avoid those kind of situations. That is why the strategic decisions, and especially the ones regarding to the location of warehouses, should be made carefully and through different studies in order to get the best location which would achieve the best reduction in terms of cost. For carry on the studies regarding to the best location, an important amount of data is required, especially the demand through the last years, to be able to differentiate between other issues that could affect the location decisions, like seasonality or trend in demand.

The capacity of the warehouses is an important question that usually determines the location of the warehouses or the addition of a new one. If a great capacity is needed, on the one hand, the cost of building up and maintenance cost of the warehouses are going to be significant, and also the inventory cost would be a relevant factor. On the other hand, the transportation cost would decrease since it would be possible to carry full load of containers, which will decrease the cost. However, in this particular case, the customer company has no capacity constraints in the collection points or in the factories since the resources are just hold for a short period of time, and thus, they do not have any inventory associated cost.

Other factors, such as fuel price increase, could affect the decisions of placing a new warehouse since they affect the overall logistics networks. Ideally, an equilibrated logistics networks is the one that is not affected strongly by risk factors, such as fuels price variations for example. By adding new warehouses to the existing logistics structure, it is possible to see its influence by looking at the response on the overall cost when there are changes done by the risk factors.

For studying the best location of the warehouses, it is important to know the performance of each location individually, so decisions regarding each one location could be made with objective data that the manager of the customer company could use as Key Performance Indicators, like for example, the associated cost per order on each location, the volume of material processed by certain locations, etc.

However, there are some situations where this data is not available because the company has not been performing the activity for a long time or because they do not have an appropriate information technology system that is able to storage and process those data, since usually those systems are quite expensive and requires big investment on information management. Other possible scenario could be when a company plans to implement its activities in another country and only have a small amount of data available based on forecasting. In any of those cases, the data of the performance could be obtained by modelling the problem ,and later with the use of a software, run a simulation which would find which is the best location for each order, and thus will optimize the overall performance. This simulation would give the best performance possible with the company estimated numbers of cost and resources.

The optimal assignments of the orders to the best locations depends on many factors such as the actual costs that influence the transports cost or the different ways of procedure. Ideally, a good indicator of the performance of each location, which would determine if the place is well located, is the existence of overlapping areas between the influence zones of each location. If this overlapping areas are frequents and numerous, this would mean that the performance of the overall logistics network is quite poor and thus there is room for improvement of the current performance, in case the activity is already existing or the estimated one in case they are plans for expand to another country.

It is also possible, thanks to the simulation of the modelled problem, to see which changes would lead to diminish those overlapping areas or which factors are the ones who have more influence on this issue. Once the overall and individual performance that each figure plays on the logistics networks is identified, decisions such as change locations of the warehouses, build more warehouses, set the capacity of the trailers to more or less volume, etc., could be made, so the importance of having a good mathematical model that describes accurately the performance for the company is a key issue.

Once the information of the orders assignments to the best location is available, in this case obtained by the simulation, the orders are required to be assigned to the transport companies. The company distributes the incoming orders to the different transport companies available. The different criteria followed when it refers to the assignment of the orders to the set of transports companies is the main cause of the unbalanced salary at the end of the term, and this can result in problems among the different transport companies, so it could be appreciated the importance of having a good criteria when referring to the distribution of the incoming orders among the different transports companies, which will be able to lead to small differences in the incomes or even no differences at all.

As it was seen by all the description above, the performance of the logistics networks is a continuous trade-offs between many factors, thus it is hard to find real optimization of all factors, and especially if they are studied individually but not the impact they will have in the overall performance. In this work, a thorough study of the transport issue is going to be done, and later the influence of other factors are going to be studied in order to set the influence of each factor, both locally and globally, in the logistic network of the customer company, in order to achieve the total optimization of the logistics networks.

2. THEORY AND BACKGROUND INFORMATION

In this section, the information required to understand the methods developed and employed in this work, as well as other information that the author thinks it is relevant to clearly comprehend the purpose of the thesis and the followed procedure, are going to be exposed.

2.1. Literature review

In this work, as it can be inferred from the introduction section, the main problem is based on a composition of many different problems, because of this fact, it was required the review of some literature that focus some parts of this problem in order to shed some light on this issues, with the final objective of being able to solve the main problem.

Information about the location problem of the possible facilities can be found widely on the literature. Some articles that were used in this project for gathering information about this issue and try to solve the different problems that appeared on the present work are the following:

"Research on Distribution Centres Location Problem" (Chen & Wang 2008).

This paper covers different previous work that were done related to the location of the distribution centres, with the consideration of multiple suppliers, and focuses on the supply transportation cost and the distribution transportation cost in the distributions centres. After building the distribution centre location model by setting the objective of minimizing cost, it solves the modelled problem by the use of an algorithm. This article was useful to give an overall idea of how to build the model that was later used in this work, and also to give a general approach of the location problem and the different possible solution methods.

"Optimal Location Planning for Self-Storage Enterprises" (Lackesa & Siepermann 2009).

This paper bases its model on binary decision variables, which were later used in this project, and uses those binary variables as possible locations, and the different models include many considerations when it comes to open a facility in a certain place, like competitors on the market and other constraints. It was useful to see the output of data in terms of the map representation and to gather information about what decision variables should be taken into account when it comes to the question of opening a new warehouse, despite the fact that in this problem those politics were not used at all. This is a recommended lecture in case the reader of this work may not be familiar with some basic concepts regarding the binary variables, and the utilization of them when it comes to the issue of modelling certain problems.

However, for the particular problem where new collection points have to be added to the logistic networks, where some facilities and warehouses already exist, is not easily found in the literature, and especially if the issue of long distance transportation with the trailer is added, then, it turns into a really specific case where not articles were found. In contrast, many articles are in literature regarding the p-median problem, which covers again the facility location problem but with the objective of minimize total cost. The articles used for this topic were:

"Solution Methods for the p-Median Problem: An Annotated Bibliography"(Reese 2006)

This article was really useful in order to get a first approximation to the p-Median problem and the different approaches to solve it. It covers the background of the problem, with the different approaches that were established, and advises the lecture of some articles related to the different techniques used when solving the problem. With the lecture of this article, the reader can understand some basic concepts about the p-median problem that were later used on this work, so it is a recommended lecture in case the reader of this work has little concepts about this issue.

"Applied p-median and p-center algorithms for facility location problems" (Dantrakul,Likasiri & Pongvuthithum 2013.)

This article covers the solution of the p-median problem by building a model and tests it with a simulation tool, by the use of different methods, like the set up cost based, when set up cost are larger than transportation cost, the p-median method, used to find the minimum total transport cost, and the p-centre method, used for locate facilities that minimize the maximum distance between the facilities and the assigned clients. All the models were developed and tested by doing a simulation, solved the problem with all the methods, and showed the results for the different approaches. This article was useful in order to gather information to build the model in terms of the different approaches that would need to be used later, and also to see the different on the final performance and behaviour of the model depending on the approach taken to build it up. It was also useful because it shows the different results of all the simulations done with the different approaches.

For the specific location of new possible collection points, the center of gravity method, also known as CoG, was mainly used, but the Weber method was also contemplated. One article that covers this problem in terms of new location of distribution centres by the use of the center of gravity method is the following:

"Study and Application of Center-of-Gravity on the Location Selection of Distribution Center" (Zi-xia,Wei 2010.)

This article shows how to use the centre of gravity method when selecting a new location for distribution centres. It makes some modifications to the centre of gravity method to take into account the variables that affect most the location for that particular problem in order to achieve the best solution possible. This article was important in order to see a first approximation of how to approach the location of new collection centres, and also for using different factors, since they can lead to different results, as it will be better reflected on the results sections. With the lecture of this article, it is possible to learn some basic concepts about the center of gravity method and its application of the location problem, which is widely used.

On the other hand, for a better understanding of other locations models, and especially the ones based on the Weber method, the following article is recommended:

"Facility location models for distribution system design" (Klose and Drexl, 2005)

The article mainly describes the state of the art of the location models for facilities, giving a huge variety of different facility location models depending on different factors that are based on, and explain the different models, as well as the continuous locations models, (where the Weber method is included), the network location models, and the mixed-integer locations models, as well as their different possible applications. The reading of this article is highly recommended since it will help the reader to understand some specific concepts that will help to the understanding of the model later developed in this work, in addition to the main purpose of the article that was the understanding of the Weber method for the location of new facilities.

For the issue of establishing the real road distance in the calculated distance, the article used as reference was the following.

"Selected country circuity factors for road travel distance estimation" (Ballou ,Rahardja & Sakai 2002*).*

This article was selected because it covers how to calculate the circuity factor by using the value of the real road distance and the distance in kilometres. It was useful also for using it as a comparison between the obtained number in the literature and the one calculated for this problem.

Other important documents that were used were documentation materials of the software employed, in this case the GLPK as it will be seen in later sections. This materials can be found when the software is downloaded, and they may help to comprehend the programing code that was used in the model developed in the software.

2.2. Definition of the problem

The customer company has two primary factories along Norway, where the resources are treated in order to obtain the final product. This two primary factories are located in Storsteinnes, the one in the north, which from this point in the text is going to be identified also as "Factory 2" , with the coordinates: (69.24081, 19.23436), and in Ingeberg, the one in the south, which has the coordinates: (60.83923, 11.09972) and that is going to be identified with the label "Factory 1".

In addition to the factories where the resources are processed, the customer company has some collection points where resources can be stored in order to be able to respect the time window of three days to collect the resources which is set by the law.

The existing collection points are described in the following table classified by the area number, and from this point, they will also be known as collection point 3, 4, 5 and 6 respectively.

Table 1. Coordinates of collection points.

Area	Latitude	Longitude
8	58.63039	5.599
9	59.53082	5.84245
12	62.98124	8.65731
13	63.81768	11.00581

Figure 1. Location of factories and collection points

The collection points are ideally located near the orders in order to reduce the transportation cost, and also for being able to operate within the limited restriction of the time window. In this case, a set of data consisting on the orders of a two-week time period was given in order to analyse de performance of the logistics network. This set of data can be used as an approximation of how the orders behave among all the year if it is assumed that there are no seasonality on the demand and the set of orders is quite representative of the distribution of orders in the whole year, it will help to determine the performance of the logistic networks in order to discover possible points of optimization. The set of data includes information about the locations that request the services of the customer company for collect the dead animals, the weight of the order and to whom transport company it was assigned. The location of the farm that request the services comes in form of coordinates, and they are going to be converted into distance by the use of a formula and later corrected to the real driving distance, since usually it is not the same than the geographic distance since it depends of the status of the roads or the geography of the area. By the use of a factor, called in this problem the circuity factor, the real driving distance will be reflected.

It is crucial to point out that all the orders which are carried first to the collection points, later must be carried to one of the factories. Because of this particular way of procedure, all the orders assigned first to the collection points are going to be taken after they are collected to the Ingeberg factory, or factory 1, which is the most logic procedure because it will reduce the costs since it is the nearest factory to all the collection points. These resources are carried from the collection points to the factories by trailers, and, since there are no time requirements once they are collected from the farms with the truck and placed in the collection points, they could be sent to the factory by different operating procedures. On the one hand, it is possible to wait until one trailer is full before taking the whole load of resources to the factory, in order to achieve a reduction of the cost by optimizing the utilization rate of the capacity of the trailer. This way of performing is also known as full trailer load or FTL .On the other hand, just carried them whenever they are necessary due to a lack of the resource to produce the final product or other kind of issue that could occur.

As it was previously said, the performance of each location is going to be studied through the results obtained from the simulation. In this case, there are no actual information of the current performance in Norway that could be used to compare the results obtained for the simulation to the real ones, and thus search for possible performance improvement opportunities. Instead, the results of this simulation are going to be used to evaluate the estimated performance of the overall logistic network that the customer company has estimated. This is going to be done by looking at the existence of overlapping areas that those estimated figures could have and the individually performance of each location in order to seek for improvement. In addition, the performance is going to be analysed, both in a overall and individual way, of each location, by adding a new collection point to see the influence it would have by looking at the total cost and also the overlapping areas. Other factors, such as capacity of the trailers or variation of fuel cost are going to be studied also to see the impact they would have in the overall performance, since this can affect also the final strategic decision of adding a new collection point depends of the effect they have on the overall logistics cost.

In addition to the location problem, another issue is the distribution of the orders within the transport companies.

The customer company way of procedure consist on assigning an incoming order to one of the ten private transport companies which work with the customer company. The different criteria followed by the companies to assign the orders within the transport companies, can lead to a unequal distribution of the cost spend in each transport company, due to a big difference among the total amount of kilometres each transport company is doing at the end of a time period, since all the orders do not have the same amount of distance or the same number of stops and loads duty, and thus it will impact on the overall cost.

2.3. Cost structure

The cost structure refers to the different parts that form the total cost which will affect the customer company in this specific problem.

It is important to claim out that for this problem, all the cost have been converted in euros using and exchange rate of the Euro- Norwegian Krone of 8.78 NOK per Euro, so in case it is necessary to update the value of the currency for a more accurate visualization of the cost, this issue has to be taken into account.

2.3.1. Depreciation cost

The depreciation cost is defined as a decrease, in a certain period of time, in the value of an asset caused by its utilization. The total depreciation cost for this problem consists on the depreciation cost of the following parts:

- Truck
- Container
- Trailer
- Equipment

And the rate of depreciation for all the parts contemplated within the structure of the depreciation cost was settled into a value of 20% per year.

2.3.2. Fixed cost

The fixed cost is defined in this case as the cost that does not make any variation with the fluctuation of the services the company performances. For this problem, the fixed costs consist on:

- Interest rate for capital (set as 6%)
- Interest rate for working capital (set as 10%)
- Insurance fees (estimated as 2200 € annually)
- Vehicle tax fees (estimated as 2200 € annually)
- Administrative costs (estimated as 3700 € annually)
- Garage, maintenance, other items (estimated as 1700 € annually)

2.3.3. Variable cost

A variable cost is defined as the cost which varies depending of the amount of service or products done by the company.

The variable costs for this problem are:

- Fuel costs
- Urea cost
- Maintenance costs
- Tyre surface replacement
- Other variable costs

2.3.4. Labour cost

The cost of labour could be briefly defined as the total cost related to the work of employees, including taxes.

The labour costs for this problems are

- Driver's average salary
- Salary additional costs
- Daily allowances and lodging costs

2.3.5. Transport cost

The transport cost is defined as the amount of money which is spent on to move one quantity of material from one place to another.

In this case, the transportation cost have two main components, the truck and the trailer.

2.3.5.1. Truck

The first one is the transportation cost which is spend in the need of collecting the resources from the farm and placing them into the collection points or the factories. This task is going to be performed by a truck, and, the costs that form the truck cost are the loading cost and the cost per kilometre.

- Cost per kilometre

The transport cost per km for the truck is a variable cost which depends on the all costs previous explained. The cost per kilometre is going to be mainly influenced by the fuel cost, which is a cost which can fluctuate widely through short period of time, is going to be a determinant factor in the total cost of transport. For a first analysis, the fuel cost was settled in a value of 11.072 NOK per litter.

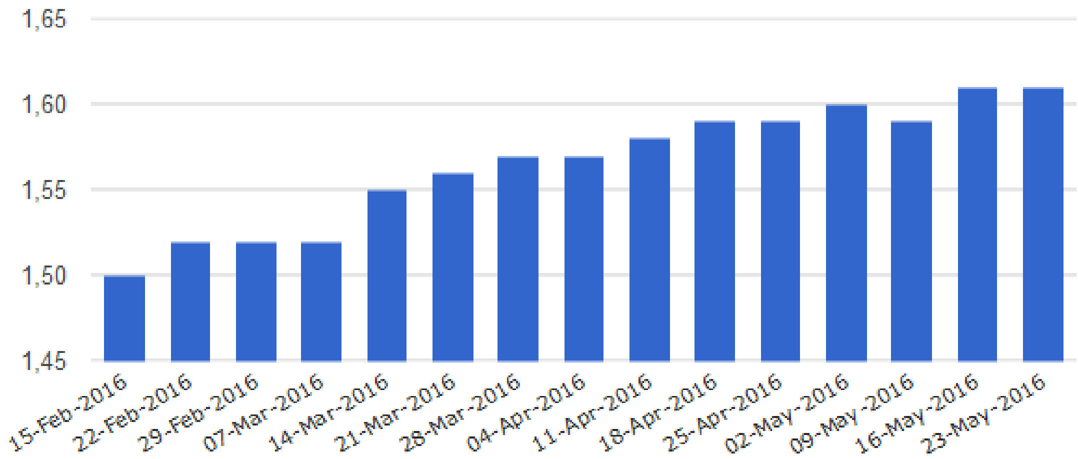


Figure 2 . Variation on fuel price in Norway. (Globalpetrolprices.com, 2016)

The steps followed for calculating the average cost per kilometre are going to be explained later in the methods section.

- Cost per load of truck

Regarding to the loading cost for the truck, it is not a value given by the customer company, so an estimated value must be considered. It is assumed that 30% of the driving hours in a year are the amount of hours estimated to loading or unloading task. In addition, it is known that each container unloaded/loaded at the collection points or factories takes an extra 10 minutes of time and cost. The calculations for establishing the cost per load are explained in the methods section.

2.3.5.2. Trailer

The other transportation cost, as it was mentioned previously, is the one which takes into account the cost spent by taking the resources that had been collected from the farms and placed them into the collection points, and carried later to the factory in order to process the resources and have the final product. This transportation, since it does not have a time restriction, can be made with a long trailer in order to reduce transport cost by having a FTL transportation, or just can pick the containers left by the trucks, with no matter if they are full or not, in the collection points. Both scenarios are going to be studied in this project.

Like in the truck case, the trailer cost also have two main components, the cost per kilometre and the cost per loading. The procedure followed by setting this two cost are going to be explained in the methods section.

2.3.6. Set up cost

The other cost that defines the total cost is the set up cost. The setup cost is defined here as the cost of setting a collection point in certain area. This cost has included the land cost, the building or maintenance of the facility and other cost. The setup cost for all the collection points in this case is going to be of 5000 € per year according to the information provided by the company.

2.4. Transport companies

The transport companies that work with the customer company are the following:

Table 2. Different transport companies operating.

Transport Company
Bakkevold
Broderne Nervik
Edvardsen
LitraTransport
Surnadal
Tenden
Herredsvele
Danielsen
Nervik
Hellenstransport

For the fair assignments problem, it was supposed that the companies are responsible for every order from the beginning, by picking it at the farms, to the end, by placing the order either in the factories or in the collection points. In addition, it was supposed also that all the transport companies are in possession of at least one trailer and one truck, and they are responsible for the transportation of the orders they took into the collection points to the factory by the trailer, so they are able to make both kind of transportation. In addition, since the location of the transport companies is not known, it was also supposed that all the transport companies are able to make any order, regardless of the location. Related to the issue of the unknown locations of the transport companies, it is important to notice that, in this problem, the distance of going from their initial location to the farms by the truck, and to go from the factories to their home by the trailer, is not going to be taken into account since the initial and final location of the drivers of the transport companies will affect widely the final results.

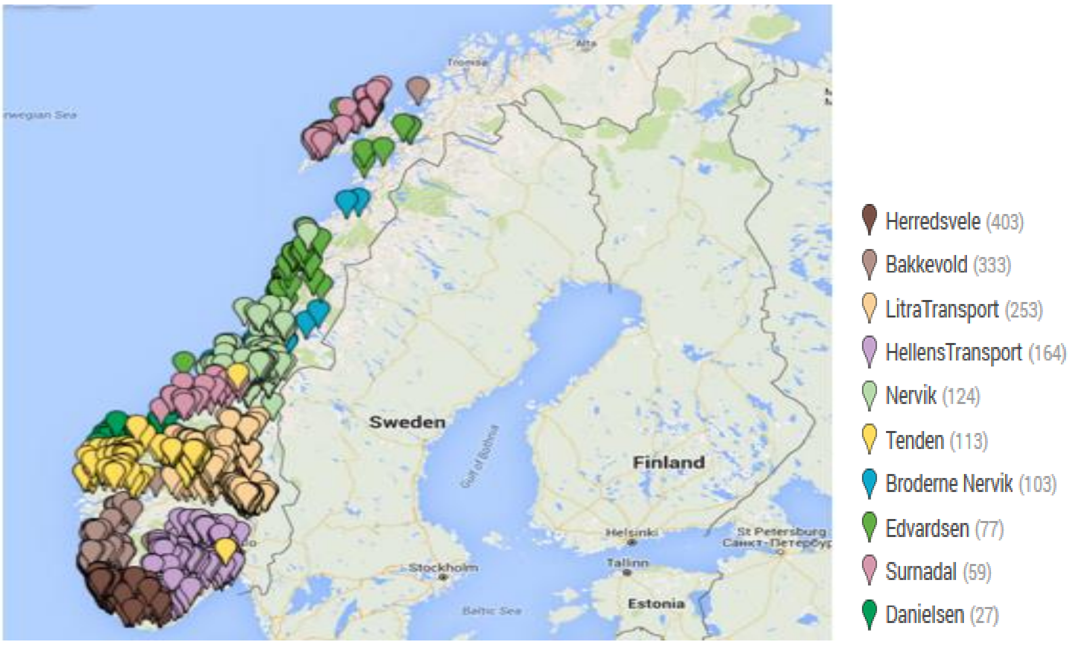


Figure 3. Distribution of the orders within transport companies.

The above figure represents the current distribution of the orders through the different transport companies for this problem. As it can be observed , there are important differences in the number of orders that, as it will be explained on the methods section, leads to big differences between in terms of cost between the companies, and thus will impact the final income each driver for the different transport companies perceives at the end of the term, which could lead, as it was previously explained, to diverse problems between the staff of the different transport companies, in case one transport company is not making enough profit due to the fact that other companies have a big associated cost ,since some companies take more orders as a result of a unfair assignments of the orders.

3. METHODS

In this chapter, the different methods followed for accomplish the different needs required for optimizing the logistic network, like the establishing of the different cost, the calculation of distance with the coordinates, the use of a circuity factor, the model developed, the method for setting the location of an additional collection point and the criteria needed for achieving a fair distribution of the orders within the transport companies are going to be explained.

3.1. Costs calculations

As it was previously described, the cost of the truck and the trailer per kilometre and per load have to be established. In this section, the steps and assumptions made for estimating both costs are going to be explained.

3.1.1. Truck Cost per kilometre

The cost per kilometre of the truck is function of many different cost as it was explained before. For this case, the main variables used where the following:

- Total billable kilometres per year: 112500.
- Average fuel consumption: 33 litres/100 km.
- Average speed: 65 km/hours.
- Drivers average salary: 23.31 €/hour.
- Additional salary cost: 60% (social security, pension fees).

- Daily allowances and loading cost: 2000 € per year.

- Fuel cost: 1.29 €/litre.

- Profit Margin: 10% of total cost.

- Average Loading/Unloading time: 30% of driving hours.

By having the number of driving hours per year (dividing the billable kilometres by the average speed), it is possible to calculate the total driving hours per year. To this number of driving hours, an additional 30% corresponding to the loading and unloading task hours have to be added. Later, all the variable fixed, depreciation and labour cost that were previously defined are summed in order to calculate the total annual cost before the profit. By adding the margin profit of 10%, the total annual cost is obtained.

If the total annual cost is divided this by the total billable annual km, a cost of kilometre is obtained, with a value of 1.8979 € per kilometre, and the total cost per hour when driving is 94.895 € per hour.

3.1.2. Truck Cost per Load and unload

It is realistic to think that the cost per hour when the truck is loading should be less than when the truck is driving; the reason is because while loading, there are not variable cost.

For establishing the cost per load, the same assumptions as for the cost per kilometre were made, but, in this case, the variable costs as, fuel consumption, maintenance or other variable cost were not taking into account. Following the same procedure as before but excluding the variable cost, the total cost per hour when loading has a value of 66.793 € per hour.

For calculating the cost per load, the time per loading was necessary, so the following steps describe the procedure for estimating the cost for loading.

It was supposed that every stop at the farm takes 20 minutes. In addition, 5 minutes per loading each animal have to be added. By doing the average number of animals within all the orders, the mean had a value of 2 animals per order, so, it is possible to conclude that at the farm, including the stop time and the loading time per animal, an average of 30 minutes or 0.5 hours are required for stop and loading.

Table 3. Distribution of animals within the orders.

Animal	Times appeared	Number of total animals
Sheep	258	303
Cow	49	49
Small cow	113	294
Poultry	36	36
Kylling	23	92
Sau	227	677
Ku	80	82
Hest	10	50
Gris	117	234

Regarding to the unloading time at the collection points, it is also known that the unloading time at the stock points has an increase of 10 extra minutes than the average unloading time.

The drivers leave the load at the stock points, which an average time of 0.4167 hours that was estimated by counting the stop time of 10 minutes and 5 minutes for leaving the container, plus a 10 extra minutes increase.

By multiplying the total cost per hour when loading for the average time required for the loading and unloading task, the average cost per load for the truck was set as 61.227 €, where 33.397 € corresponding at cost per loading at the farm and 27.831 € are for unloading at the collection points. The total average time of stop, loading and unloading the order is 0.9167 hours, independently of the driving time spent while doing the order.

In terms of analysis, it is better to have a fixed cost for the loading task than to have a variable value which depends on the driving hours as it was first estimated. The reason of making this approach is because, while some orders can take more than 3 driving hours (which is the amount of driving hours that will give the value of 0.9167 hours of loading time) and thus be overestimated, other orders can have a lower value of the driving time required and as a result, the cost of loading would be underestimated.

3.1.3. Trailer Cost per kilometre

For the trailer cost per kilometre, the same assumptions as for the truck cost were made but changing the following data:

- Total billable kilometres per year: 180000.
- Average fuel consumption: 40 litres/100 km.
- Average speed: 65 km/hours.

By doing exactly the same steps than in the chapter 3.1.1, the average trailer cost per kilometre has a value of 1.838 euros, which is less than the truck cost per kilometre since it is expected that more kilometres are going to be covered.

3.1.4. Trailer Cost per Load

As it was said in the introduction section, two approaches are going to be contemplated: dispatching FTL or picking the containers as they are left by the trucks in the collection centres. For this last approach, it is worth to remark that the trailer can carry up to 3 truck containers. It is also critical to notice that in this model, there are not inventory associated cost (neither inventory holding cost, safety inventory cost nor pipeline inventory cost).

The approach for calculating the average cost per load in the trailer is explained in this section. The same assumptions of no fuel consumption or other variable costs that were followed for the truck cost per load were followed here, and by carrying out the same steps done in the truck section, the average cost per hour when loading resulted in 60.3878 € per hour, which is also less than the truck cost per hour when loading.

3.1.4.1. Full Trailer Load.

For considering the trailer as a FTL, there are two possible approaches:

I. The containers that the trailer are going to carry are manually fully loaded.

II. Container left by the truck is already fully loaded.

Manually Fully-loaded containers.

This approach was based on the way of procedure where the animals located at the collection points are unloaded and placed in the trailer container until it is full. The following table represents the steps followed by calculating the average time of loading the trailer manually until it is full.

Table 4. Average time per loading until the trailer until is full.

	Average weight per animal(kg)	Number of animals until full load	Probability of that animal in the order	Time(min) per loading each animal	Time in the order for loading(hours)
Sheep	58.08580858	206.5909091	0.282584885	1.161716172	1.13033954
Cow	520.4081633	23.05882353	0.053669222	10.40816327	0.214676889
Small cow	133.5034014	89.88535032	0.123767798	2.670068027	0.495071194
Poultry	250	48	0.039430449	5	0.157721796
Kylling	62.5	192	0.025191676	1.25	0.100766703
Sau	23.92909897	501.4814815	0.248630887	0.478581979	0.994523549
Ku	503.6585366	23.82566586	0.08762322	10.07317073	0.350492881
Hest	120	100	0.010952903	2.4	0.04381161
Gris	103.2051282	116.2732919	0.128148959	2.064102564	0.512595838
			1		**4**

As it can be seen, the average number of kilograms per animal was calculated according to the orders information, later, it was estimated a time per loading each animal based on the kilograms of every animal, as it is not the same in terms of time to load a big cow of 500 kilograms and place it in the container than a small animal of 50 kilograms. Once that was done, the average time for each animal in an order was calculated and the total sum gives a value of 4 hours for completely load the trailer whose capacity is 12 000 kilograms.

To this loading time, an additional 10 minutes for the trailer to stop at the collection point, plus 15 min for the trailer to pick the 3 containers, plus the 10 extra minutes required were added.

For the unloading task at the factory, it was estimated that trailers left the container there. The time is supposed to be slightly higher than when the truck leaves only one container, so an average, 35 min were estimated or 0.58 hours,

So in average, for the fully-load-manually approach, the estimated cost per load was settled in 301.93 € for a total 5 hours' time. Note that this value can vary depending on the average time per load for each animal estimated, which as a number that was supposed based on the kilograms but not on the kind of animal.

The approach where the containers left by the trucks in the collection points are already fully-loaded is not going to be contemplated, since in this model it is not realistic, because, as it will be explained later on the model section, one order is going to be carry by one truck, so consider that the truck container is full by just doing one order is not feasible in this model, and could lead to not valuable results.

3.1.4.2. Not FTL

For this approach, which seems more realistic with the operating procedure the customer company currently works, it was just estimated that the trailer picks the 3 containers as they were left by the truck and later left them in the factory.

An equal time for loading and unloading were settled, corresponding to a total of 70 minutes or 1.16 hours, which correspond to 70.45 € per load if it is multiplied by the value of cost per hour when loading.

The average weight of each container is 250 kilograms according to the data set of orders, so, it can be estimated that the average capacity would be 750 kilograms since the trailer carries 3 containers.

The following table resumes the costs calculated in this section:

Table 5 . Costs structure in euros for the different approaches.

Cost		Per km	Per Load
Truck		1.8979	61.227
Trailer	Full load	1.838	301.93
	Not full		70.45

It is remarkable that depending of the approach followed, the load cost can be the 22, 5% the cost, which will give different results for the simulated model.

3.2. Distance

In this section, the different methods used for calculate the distance in kilometres are going to be explained.

3.2.1. Harvesine formula

In this problem, the different locations of the orders, collection points and factories are given in terms of latitude and longitude. In order to do the calculations easier for the software used for the simulation, this coordinates were converted into kilometres following the next procedure based on the *Haversine* formula:

The *Haversine* formula is an equation that allows to calculate the distance in kilometres between two points from their longitudes and latitudes.

The distance (D) in kilometres can be calculated using the following formula:

$$D = 2 * r * \arcsin(\sqrt{\sin^2\left(\frac{\varphi 2 - \varphi 1}{2}\right) + \cos(\varphi 1) * \cos(\varphi 2) * \sin^2\left(\frac{\lambda 2 - \lambda 1}{2}\right)}) \quad (1)$$

Where:

$\varphi: Latitude, in\ radians$

$\lambda: longitude, in\ radians$

r: radius of the earth (6356 km)

3.2.2. Circuity Factor

Since the distance calculated between the two points, by the use of the Haversine formula, is not always the real distance of travelling because the average driving distance has a different routing and roads than the straight distance, and the importance of the different geography of certain areas, a corrective factor for this issue should be applied. The factor is called *Circuity factor*, and is the ratio between the distance from two points, and the real distance it takes to cover them by road. In literature, some articles can be found where a value of a circuity factor is given depending of the country. The following image represent the average value of the circuity factor for different countries around the world.

Circuity factors for selected countries and regions

Country	Number of points	Average circuity factor	Standard deviation
Argentina	66	1.22	0.15
Australia	77	1.28	0.17
Belarus	21	1.12	0.05
Brazil	120	1.23	0.11
Canada	49	1.30	0.10
China	66	1.33	0.34
Egypt	21	2.10	1.96
Europe	199	1.46	0.58
England	37	1.40	0.66
France	9	1.65	0.46
Germany	31	1.32	0.95
Italy	11	1.18	0.10
Spain	61	1.58	0.80
Hungary	36	1.35	0.25
India	105	1.31	0.21
Indonesia	16	1.43	0.34
Japan	36	1.41	0.15
Mexico	49	1.46	0.43
New Zealand	4	2.05	1.63
Poland	45	1.21	0.09
Russia	78	1.37	0.26
Saudi Arabia	21	1.34	0.19
South Africa	91	1.23	0.12
Thailand	28	1.42	0.44
Turkey	28	1.36	0.34
Ukraine	36	1.29	0.12
United States [a]	299	1.20	0.17
Alaska	55	1.79	0.87
US East [b]	143	1.20	0.16
US West [c]	156	1.21	0.17

Figure 4. Value of Circuity Factor in different countries. (Ballou ,Rahardja & Sakai 2002).

As it can be seen, the value for Europe is too generic, attending to the different natural composition of each country forming Europe, so an approximation of the circuity factor is going to be made. For doing this, five random location points of the orders are going to be selected, and calculated the distance using the *Haversine* formula. Later, by the use of *Google maps*, the real distance for travelling between those points can be obtained, then, it is possible to estimate the average and obtain a proper circuity factor. The results can be viewed in the table below:

Table 6. Value of the average Circuity Factor calculated for Norway.

Number of the Order	Distance (km)	Driving Distance (km)	Circuity Factor
5	349,86677	515	1,471988895
35	326,938351	495	1,514046912
239	190,925344	270	1,414165319
321	324,077527	495	1,527412296
435	321,254094	461	1,435001168
		Average	1,472522918

As it can be seen, the value obtained is quite similar to the one reflected in Europe for the literature. However, this calculated value is going to be used instead of the literature value since it was calculated only considering Norway, not whole Europe, so it is expected to be more accurate. To obtain the final real distance, the distance obtained by the *Harvesine* formula was multiplied for the circuity factor calculated.

3.3. Model

After a careful review of literature, is it possible to conclude that a solution for this particular case, in which first some resources need to be collected in order to reach the time requirements, and later this resources are sent to the Factory if they are first collected in the collection points, is not found.

Some assumptions were made in order to find a solution for the problem:

- Each order has to be taken individually from the farm to the collection points or the factories.

The reason why this assumption was made is because there is not time information of when the orders were made, so in order to maintain the restriction of the time window of 3 days, is assumed that orders are taking individually by just one driver and is not possible to carry more than one at the same time by the same driver. It has to be noticed that, in case the approach was more focused on setting in a policy for aggregating the orders in order that set the optimal route for the trucks, it would be in the frame of a *Vehicle Routing Problem* (VRP) which would require much more data to develop it. As it will be explained in later chapters, once enough data is available, a dumping factor for minimizing the impact of the truck transportation could be introduced as it could represent a more realistic approximation of the average truck routing in terms of aggregating orders.

-The orders located in the collection points are going to be later moved only to the Factory 1.

The reason for making this assumption is based on distance to the Factory 1, since all the collection points are located much closer to this factory.

-There are no inventory, capacity or demand constrains from locations

The reason for taking this approach is the lack of information of the factories consumption rates of the products, the capacity of either the factories or collection points and thus, the inventory. Since the lead time for this particular problem is quite small, the cost of safety inventory and pipeline inventory will not be much relevant but the holding cost of cycle inventory, in case the number was available, would have a really strong influence in the model

For this problem, the following notation are introduced to formulate the mathematical model:

I={1..n} set of orders

J={1..m} set of location sites

F_j*: Setup cost of location for location* $j \in J$;

Di,j: Distance from order i to location j

Lj: Distance from location j to Factory 1

Cs: Cost per kilometre (in euros) for the truck

Cb: Cost per kilometre (in euros) for the trailer

Cls: Cost per load (in euros) for the truck.

Clb: Cost per load (in euros) for the trailer

Cap: Capacity of the trailer

Wi,j: Weight of order i to Collection point or facility j

a: minimum number of opened facilities

b: maximum number of opened facilities

3.3.1. Decision Variables

Because the size of the set (n= 1656 orders, m= 6 factories) the number of variables in this model exceeds the limit of the traditional solvers softwares. For this reason, the problem is going to be modelled and solved using a software package of optimization.

The decision variables in this problems are:

Xi,j: Binary variable which takes the value of 1 if order i is assigned to location j, and 0 otherwise

Yj: Binary variable which takes the value of 1 if location j is opened, and 0 otherwise.

3.3.2. Objective Function

Once the notation and the variables used were described, the objective function of the model will consist of three main terms that are described and formulated below.

3.3.2.1. Set up cost

$$\sum_{j}^{J} Fj * Yj \tag{2}$$

The first term describes the set up cost, which consists in the cost of open a location in j, represented by Fj, and if that factory is opened, represented by Yj.

3.3.2.2. Truck transport cost

$$\sum_{i}^{I}\sum_{j}^{J}(Dij * Xij * Cs + Xij * Cls) \tag{3}$$

The second term is the one who takes into account the cost of taking the orders from the farms to either the collection points or to the factories, plus the cost of loading at the farm and later unloading that order at the collection point or the factory.

3.3.2.3. Trailer transport cost

$$\sum_{i}^{I}\sum_{j}^{J}(\frac{(Wij * Xij)}{Cap} * Lj * Cb + \frac{(Wij * Xij)}{Cap} * Clb) \tag{4}$$

The third term gives notice of the orders that have been placed in a collection point, calculates the weight of the orders placed in that collection point and divides it by the capacity of the trailer. By doing this, the number of trailers that need to be used from one collection point to factory 1 is calculated, and later, is multiplied by the cost of the trailer per km and the distance from the collection point to the factory. Also, it contemplates the cost of loading and unloading the trailer.

For the FTL model, the capacity was settled in 12000 kilograms.

For the not FTL model, the capacity going to be the average weight of a container of the truck, 250 kilograms, times three, since this is the number of truck containers the trailer is going to carry, so the capacity average capacity of not fully loaded trailers will be 750kg.

This corresponds to a utilization coefficient of the trailer capacity of 6.25%, which is extremely low, especially if it is compared to the 100% utilization capacity of the estimated FTL approach. Note that this capacity numbers can differ much from reality, but they work as an estimation to see the performance of the model.

3.3.3. Constraints

The constraints of this model are defined as follows:

$$\sum_{j}^{J} Xi,j = 1, \quad \forall i \in I \tag{5}$$

This constraint ensures that each order is served by at least one facility.

$$Xi,j \in \{0,1\}, \qquad \forall i \in I, \forall j \in J \tag{6}$$

$$Yj \in \{0,1\}, \qquad \forall j \in J \tag{7}$$

The second and third constraints defines the binary variables used in this problem.

$$a \leq \sum_{j}^{J} Yj \leq b, \qquad \forall j \in J \tag{8}$$

The fourth constraint refers to set the number of opened facilities between a minimum (a) and a maximum (b) in case is necessary.

$$Xi,j \leq Yj, \ \forall i \in I, \forall j \in J \tag{9}$$

The last constraint is included to ensure that only facilities that are opened can be selected as places to collect the orders.

3.3.4. Generic Formulation

The generic formulation which is a combination of all the previous equations of the model is exposed below:

$$\begin{aligned} &\min[\sum_{j}^{J} Fj * yj \\ &+ \sum_{i}^{I}\sum_{j}^{J}(Dij * Xij * Cs + Xij * Cls) \\ &+ \sum_{i}^{I}\sum_{j}^{J}(\frac{(Wij * Xij)}{Cap} * Lj * Cb + \frac{(Wij * Xij)}{Cap} * Clb)] \end{aligned} \tag{10}$$

s.t.

$$\begin{aligned} &\sum_{j}^{J} Xi,j = 1, \ \forall i \in I \\ &Xi,j \in \{0,1\}, \qquad \forall i \in I, \forall j \in J \\ &Yj \in \{0,1\}, \qquad \forall j \in J \end{aligned} \tag{11}$$

$$a \leq \sum_{j}^{J} Yj \leq b, \quad \forall j \in J$$

$$Xi,j \leq Yj, \ \forall i \in I, \forall j \in J$$

As it can be seen, due to the large amount of variables that are involved in this model (n*m), a software for computation was needed in order to solve the problem and achieve a feasible solution.

The software used for this problem was GLPK version 4.0.

3.3.5. Software used and procedure

The software used for the optimization in this problem was the GLPK. The description of the software and specifications can be found on the webpage of the software.

> *The GLPK (GNU Linear Programming Kit) package is intended for solving large-scale linear programming (LP), mixed integer programming (MIP), and other related problems. It is a set of routines written in ANSI C and organized in the form of a callable library. GLPK supports the GNU MathProg modelling language, which is a subset of the AMPL language.* (Gnu.org, 2016.)

The code employed in this problem can be found in Appendix I.

For the processing of the data in this work, it was done manually by exporting the results obtained from the simulation in the GLPK software to a text archive, which was later inserted as input data in excel, and after analysed that data, it was uploaded to the My Maps application. A documentation of the procedure can be found at the Appendix II.

3.3.6. Validation of the Model

For validating the results obtained in the model and the results using an analytical solution, a comparison was made in order to seek possible malfunctions of the model.

3.3.6.1. Model in simple case

It is possible to analyse if the model prior developed in the GLPK works as expected. For this, some initial conditions must be set. The list of the conditions is shown below:

- *No transportation cost from farms to factories or collection points.*
- *No loading cost from farms and for collection points or factories.*
- *No set up cost.*
- *No transportation from collection points to the Factory.*

The reason to set this prior conditions is because the actual model is going to be solved in an analytical way and using the optimization tool, and since this is just to check if the model is working as expected and thus not looking for the optimal solution, if other factors are taking into consideration, maybe the assignments are different since the model will look for the optimization taking the cost into account. This is because the analytical solution is only based on distance, not costs, while the optimal solution will take the costs into account.

So, the model developed for checking the performance is as simple as the follow:

$$\sum_{i}^{I}\sum_{j}^{J} Dij * Xij \tag{12}$$

With this model, it is possible to calculate the best distribution of the orders to the different collection points and factories for the current situation taking into account only distance, since the objective function is the minimization of the total covered distance.

The results of the analytical solution are shown in the table below. The results are compared with the orders distribution that were obtained from the model solved in the GLPK.

```
number of orders that facility 1 is doing : 317
number of orders that facility 2 is doing : 85
number of orders that facility 3 is doing : 451
number of orders that facility 4 is doing : 329
number of orders that facility 5 is doing : 190
number of orders that facility 6 is doing : 284
```

Figure 5. Interface of the software with the model results

Table 7. Distribution of the order from simulation and analytical solution.

	Orders	
Location	Analytical	Simulation
1	317	317
2	85	85
3	451	451
4	329	329
5	190	190
6	284	284
Total	1656	1656

As it can be seen, the distribution of the orders under the analytical solution and the simulation is just the same, so it is possible to say that the model is working correctly.

3.3.6.2. Model with trailer transportation

If the assumption taken into consideration in the prior case of no set up conditions is kept, but now the long distance transportation with trailer is added, is it possible to seek for possible differences of how the model performances in comparison with the analytical solution. For this again, some initial conditions are needed:

- *Cost of kilometres of both truck and trailer are equal to 1*
- *Loading cost from farms and for collection points or factories is equal to 1.*
- *No set up cost.*
- *Capacity settled to 12 000.*

So the model is now as it follows:

$$\sum_{i}^{I}\sum_{j}^{J}(Dij * Xij * Cs + Xij * Cls) + \sum_{i}^{I}(\frac{(Wij * Xij)}{Cap} * Lj * Cb + \frac{(Wij * Xij)}{Cap} * Clb) \quad (13)$$

The distribution of the orders is shown in the table below:

Table 8. Distribution of the orders from simulation and analytical solutions

	Orders	
	Analytical	Model
Factory1	323	323
Factory2	85	85
Ryfylke	449	449
Bakkevold	329	329
Surnadal	186	186
Nervik	284	284
Total	1656	1656

As it can be observed, again the solutions obtained from the analytical solution and for the model solution are equal, so it can be expected that the model will work correctly when making the distribution of the orders. It can be noticed some changes regarding the solution with the simple model, since now the optimal location of the orders in order to find the minimum cost has changed.

3.4. Addition of a new collection point

In this section, the methods used for establishing the location of an additional collection point are going to be explained. As it was previously commented, in this problem two primary methods were used, the center of gravity method and the Weber method.

3.4.1. Center of Gravity method

The center of gravity model is based on the approach of calculating the optimal coordinates of the new collection point by using weighted longitude and latitude coordinates, where the weight used could be different factors, as it will be seen in later chapters. It uses the following formulas for both coordinates X and Y, which refers to latitude and longitude respectively.

For latitude, or value x:

$$\frac{\sum_{i=1}^{n} Xi * Wi}{\sum_{i=1}^{n} Wi} \qquad (14)$$

For longitude, or value y:

$$\frac{\sum_{i=1}^{n} Yi * Wi}{\sum_{i=1}^{n} Wi} \qquad (15)$$

Where the value of *Wi* corresponds with the value of the different factor used as weight, while Xi represents the latitude of the different locations and *Yi* represents the longitude.

In this problem, the different factors used for the different approaches are going to be further explained in the results sections since ,as it will be seen, the factors are selected according to the results in order to reach optimization by selecting the best location for the additional collection point.

3.4.2. Weber Method

With the Weber method, the main objective is to determine the coordinates which will minimize the weighted distance. The weights are given by different factors that could be used, as well as in the gravity center method, at the different locations. Thus, the optimal location will be given by the following equation for a set of i locations, which is the objective function which has to be solved in order to obtain the coordinates which minimize the weighted distance.

$$Min \sum_{i \in I} wi * \sqrt{(X - Xi)^2 + (Y - Yi)^2} \tag{16}$$

Where:

Wi: Value of different factor used as weight

Xi: Latitude of i locations

Yi: Longitude of i locations

Decision Variables:
X and Y: Latitude and Longitude of the center point

So the use of a solver is required, but in this case, since the amount of data is not big, traditional solvers could be used and a modelling is not required for solving the problem.

3.5. Fair distribution of the orders among the different transport companies.

In this section, an approach to try to distribute the different incoming orders among the transport companies that are actually working with the customer company is going to be made.

Instead of making a redistribution of the orders that were already given, the approach of distributing the new incoming orders was taken because, since the orders are already assigned, it is not possible to reassign them.

The following table represents the orders that each transport company is currently doing.

Table 9. Currently number of orders assigned to the transport companies**.**

Transport Company	Number of orders
Bakkevold	333
Broderne Nervik	103
Edvardsen	77
LitraTransport	253
Surnadal	59
Tenden	113
Herredsvele	403
Danielsen	27
Nervik	124
Hellenstransport	164
Total	1656

Once the results of the model are obtained, it can be calculated the amount of kilometres each transport company has completed for doing the assigned orders, and after, calculate the total cost spent for the customer company in each transport company, which is going to be the main indicator that is going to be used to distribute the new incoming orders through the different available companies. In addition, other indicator like the average cost per order for each transport company is going to be used.

The objective will be to minimize the differences between the costs spent in the different transport companies, thus, the average cost per order of each transport company is also expected to be equal.

Finally, a decision tool was developed to make the fair distribution of the incoming orders within the transport companies.

The tool was made with the data for the case of not FTL, but the values of the capacity, truck and trailer both loading and cost per kilometre, can be changed easily as they can be defined by the user whenever some new assignment needs to be done.

It is necessary to remark the fact that in this tool, all the transport companies are able to do all the orders since the location of the transport companies is not known. In addition, all the companies are able to make both transportation, with truck and trailer.

The tool works as follows:

1) When executed, it ask for four fields, the number of the order (it can also be changed for ID if needed), the latitude (represented by X), the longitude (represented by Y) and the weight in kg of the incoming order.

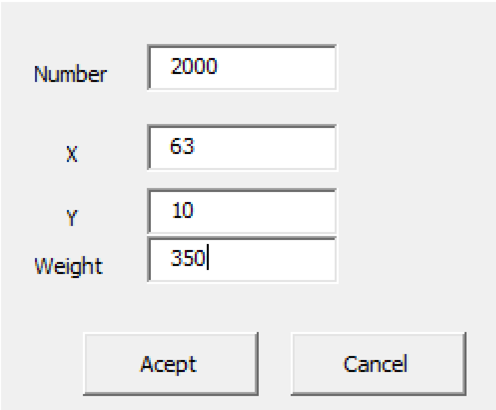


Figure 6. Interface of the tool for the input of data

2) Once the data are introduced, the tool calculates the factory or collection point where is it best to locate the order, in terms of cost, using the equation it was used for the model:

	Factory/Collection Point
Order Goes to	Factory 2

Figure 7. Assignment of the order to location.

3) Later, the program searches for the transport company with the less total cost spent by the customer company, and assigns the incoming new order to that transport company:

	Transport Company
Assigned to	Danielsen

Figure 8. Assignment to transport company

4) Once the order is assigned to a transport company, the new total cost of that transport company is updated, as well as the average cost per order. Those two

indicators could be used in order to make visible how the difference of the cost between the different transport companies is reducing.

5) On the final step, a resume with the information of the order number, the, latitude, longitude, weight, to which location is going and which transport company is taking the order is created and it can be possible to introduce a new order if it is desired.

Number of order	LATITUDE	LONGITUDE	Weight	Goes to Location	Assigned to Transport Company
2005	61	9.45	75	CollectionPointAdc	Danielsen
2004	60	15	500	Factory 1	Surnadal
2003	60	9	100	Factory 1	Danielsen
2001	60	1	50	Collection Point Su	Danielsen
2000	63	10	350	Collection Point Ne	Danielsen

Figure 9. Example of the information of the incoming orders.

4. RESULTS AND DISCUSSION

In this section, the result and the discussions of the different solutions obtained by implementing the different approaches and methods described in the previous chapter are going to be explained.

4.1. Model results

Thanks to the simulation done by using the software and the modelling of the problem, it is possible to obtain a wide variety of different data for a later analysis.

The two approaches that were explained in the methods section are going to be analysed for a better understanding of the performance of the logistic networks. Both approaches are also going to be compared between each other.

4.1.1. FTL approach

First, the results for the approach where the trailers are FTL is going to be contemplated.

In the table below, the results of the cost disaggregated by each location are shown, divided into the set-up cost, transport cost of the truck and the trailer, and the total cost.

Table 10. Results of the cost from the simulation for the FTL approach.

		Transport			
Location	Set-up	Truck	Trailer	Total transport	TOTAL
1	0	105010.68	0	105010.68	105010.68
2	0	52946.58	0	52946.58	52946.58
3	5000	72128.77	8968.32	81097.09	86097.09
4	5000	79847.25	4246.06	84093.31	89093.31
5	5000	75446.37	3637.12	79083.49	84083.49
6	5000	77041	8344.91	85385.91	90385.91
Total	**20000**	**462420.65**	**25196.41**	**487617.06**	**507617.06**

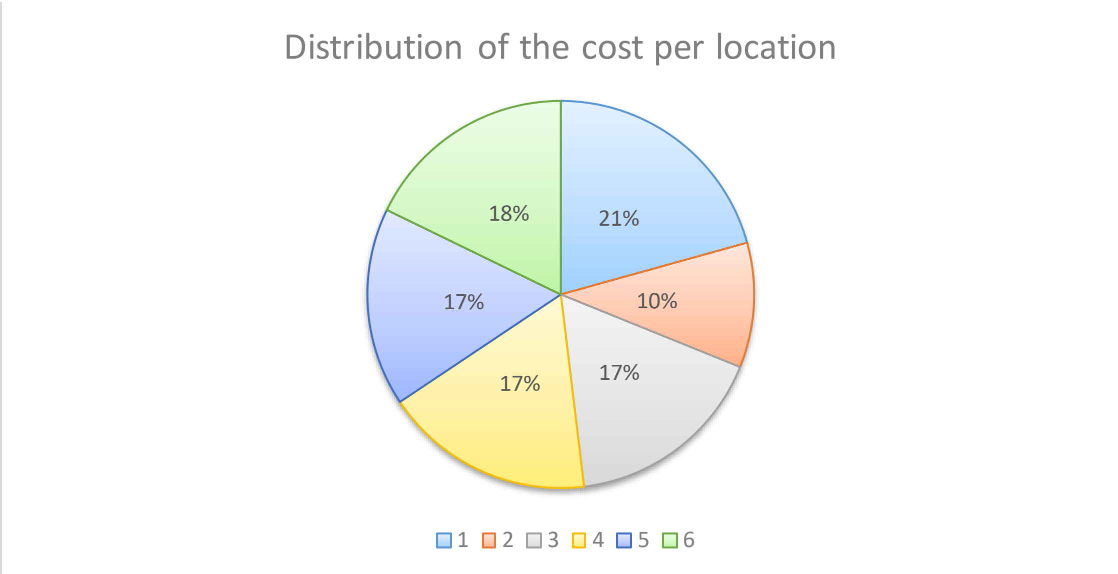


Figure 10. Distribution of the cost per Location

It is important to notice that there are no set up cost for factories 1 and 2 since the set up cost was given for the collection points, not for the factories. In addition, there are not trailer cost for both factories since the direct orders that are carried there are processed directly with the truck.

As it can be seen, the biggest influence in the cost correspond to the Factory 1, despite the absent of set up cost and trailer transport cost, so the influence of the truck cost in the Factory 1 is remarkable.

Since the transport cost is the biggest cost, it is possible to represent the influence of the transport cost in each location in a graphic.

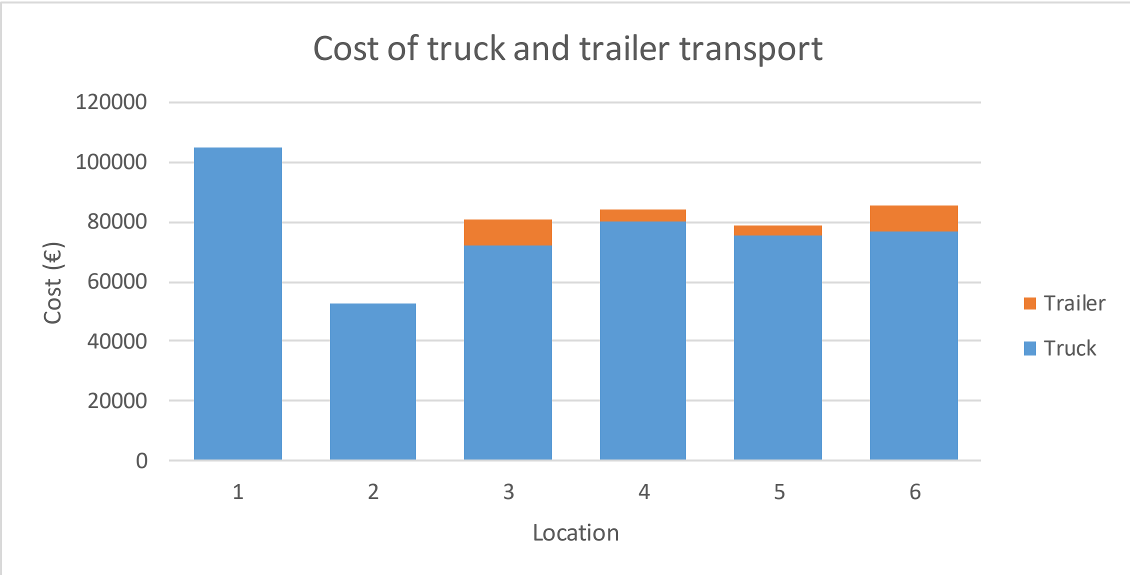


Figure 11. Distribution of Transport Cost by location.

Since the effect of the transport cost is the most influent factor, it can also be disaggregated in the two components that form the transport cost, the *loading cost*, and the *distance cost*. The results of the disaggregation can be seen in the next table:

Table 11. Distribution of Disaggregated Transport Cost in by location.

	Truck			Trailer		
Location	Load	Distance	Total	Load	Distance	Total
1	19960	85050.7	105010.7	0	0	0
2	5204.29	47742.3	52946.6	0	0	0
3	27490.9	44637.9	72128.8	1980.16	6988.16	8968.32
4	19960	59887.2	79847.2	1085.69	3160.37	4246.06
5	11388.2	64058.1	75446.3	1063.05	2574.07	3637.12
6	17388.5	59652.5	77041.0	2103.45	6241.46	8344.91
Total	101391.89	361028.7	462420.6	6232.35	18964.06	25196.41

The following figure represents the impact of both the loading and the distance cost in the total truck cost by each location. Also, the results in terms of percentage are shown so it is possible to view the distribution of the truck cost by each location, which have a really similar distribution to the distribution of the cost per location in terms of percentage that was showed in figure 10.

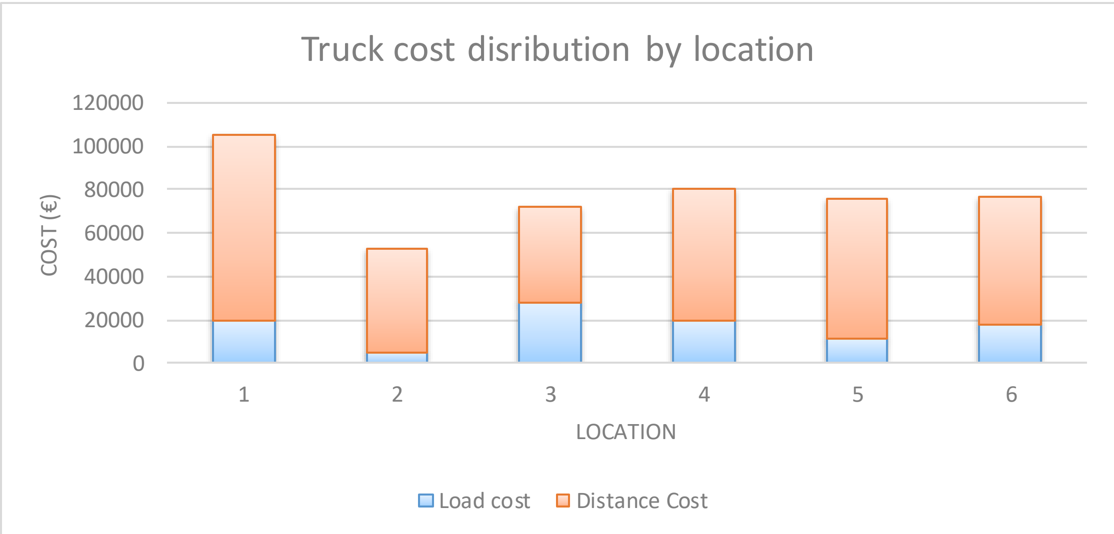


Figure 12. Truck cost distribution by location.

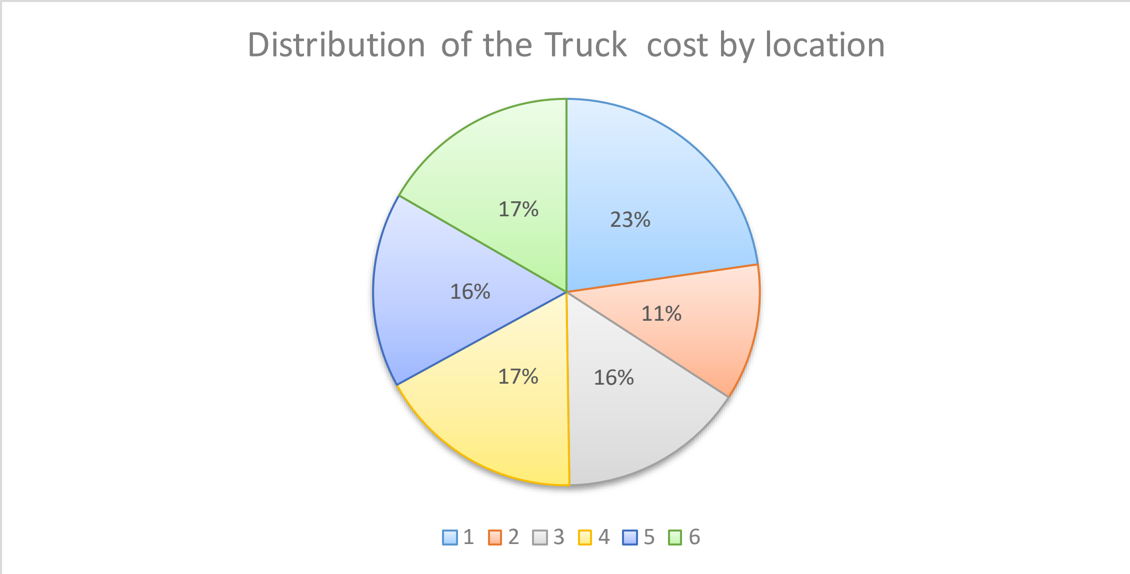


Figure 13. Distribution of total truck cost by location.

As it was explained earlier, the influence of the factory 1 is the biggest since it has the biggest transport cost associated despite the fact that there are not trailer cost on that location, which means the truck cost, and thus the distance associated to the factory 1 in this approach is quite remarkable.

The same analysis is done with the trailer cost, and the results obtained are represented below. It is important to remark the absence of the both factories since on the trailer cost, trailers are only shipped from the collection points.

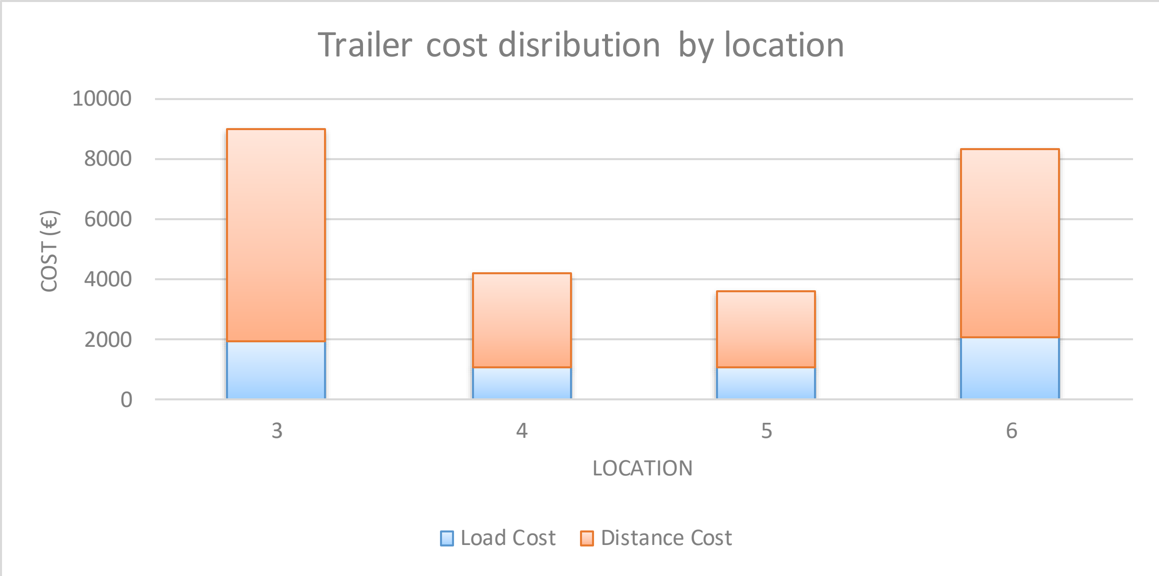


Figure 14. Trailer cost distribution by location.

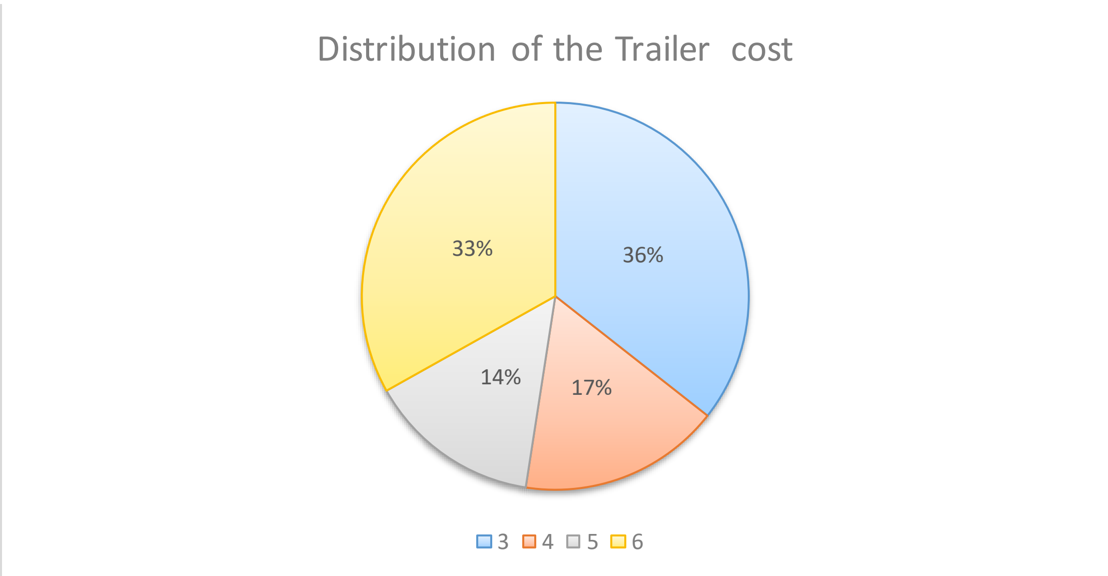


Figure 15. Trailer cost distribution by location.

The impact of the all the transport cost, disaggregated in the distance and load cost for each location, in the total transport cost of the problem is resumed in the table below in terms of percentages.

Table 12. Impact of loading, distance in the total transport cost for trucks and trailer by location in terms of percentage.

	Truck			Trailer		
Location	Load	Distance	Total	Load	Distance	Total
1	4.09%	17.44%	**21.54%**			
2	1.07%	9.79%	**10.86%**			
3	5.64%	9.15%	**14.79%**	0.41%	1.43%	**1.84%**
4	4.09%	12.28%	**16.37%**	0.22%	0.65%	**0.87%**
5	2.34%	13.14%	**15.47%**	0.22%	0.53%	**0.75%**
6	3.57%	12.23%	**15.80%**	0.43%	1.28%	**1.71%**
TOTAL	20.79%	74.04%	**94.83%**	1.28%	3.89%	**5.17%**

By analysing the table above, it is remarkable how the truck cost represents more than 94 % of the total transport cost, and of this high percent, most of the cost represents the distance cost by factory 1, but the total loading cost of the truck is still bigger than the total trailer cost, where the influence of the loading cost of the trailers in the total transport cost seems really small, due to the small number of trailers required for shipping. Also the impact of the distance cost, and thus the total cost of the trailer, is still really small on the total cost of the transport, as it can be seen on the value of the percentages.

In addition to the cost, other variables like the number of orders, total kilometres or weight managed by each location can also be studied as it is shown in the table below:

Table 13. Distribution of orders, kilometres and weight in each location.

Location	Nº of Orders	Nº Kilometres			Weight(kg)		
		Truck	Trailer	Total	Truck	Trailer	Total
1	326	44813.04		44813.04	85150		85150
2	85	25155.32		25155.32	14300		14300
3	449	23519.6	260297.67	283817.27	78700	78700	157400
4	326	31554.48	155887.32	187441.8	43150	43150	86300
5	186	33752.12	73984.8	107736.92	42250	42250	84500
6	284	31430.81	138431.3	169862.11	83600	83600	167200

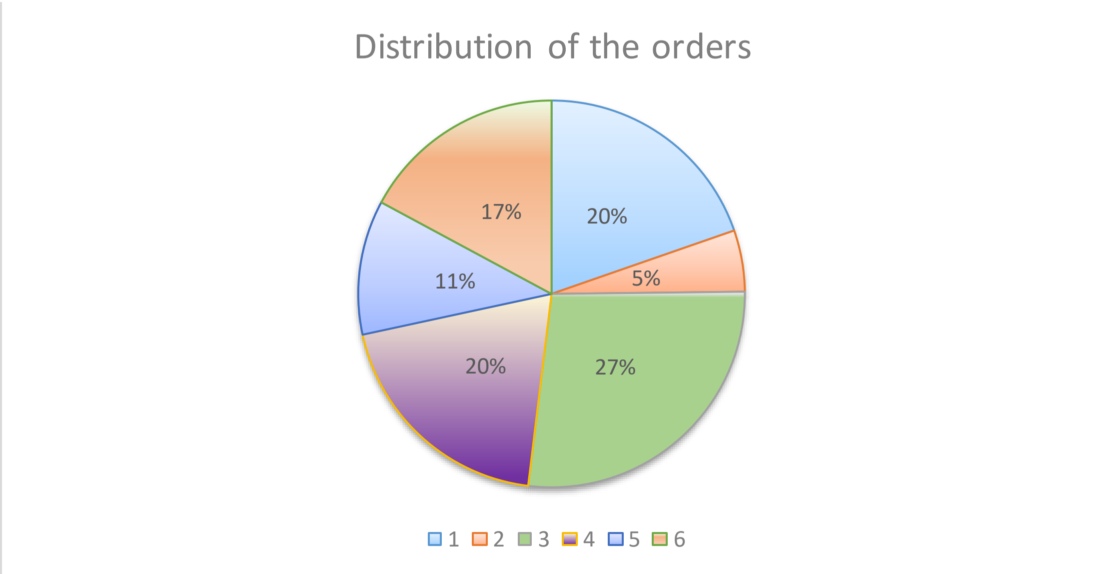


Figure 16. Distribution of the orders by location in terms of percentage.

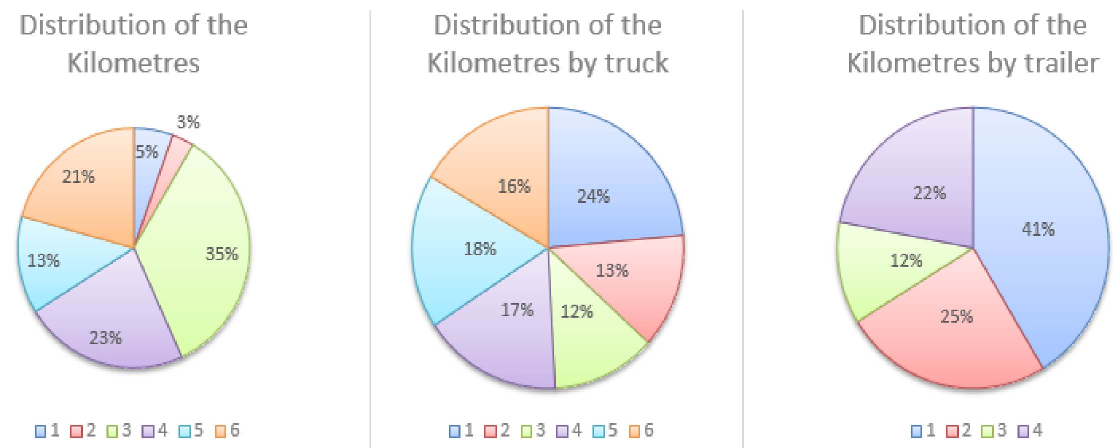


Figure 17. Distribution of the kilometres by location in terms of percentage.

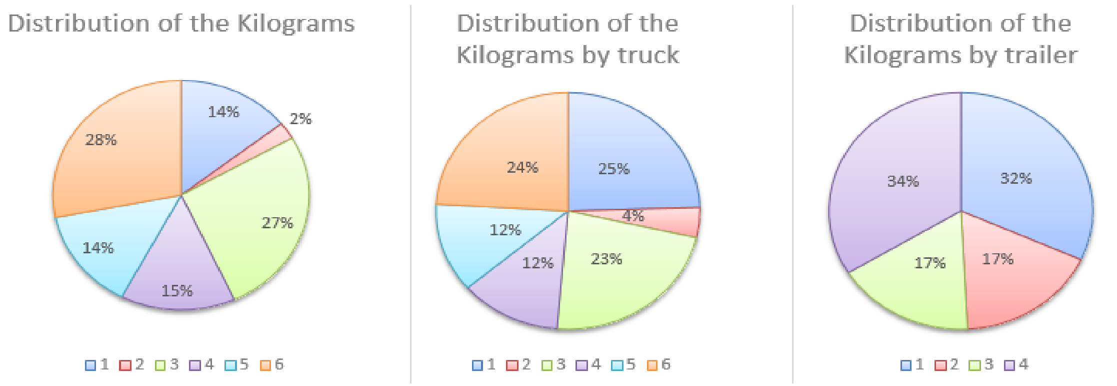


Figure 18. Distribution of the weight by location in terms of percentage.

The influence of each factor can be seen in the graphics above. It is important to remark how despite having the least number of orders and weight, the distance covered by the factory 2 goes up to a 13% influence. This is because the factory number 2 is located far away and has no collection points near it, so the orders that are sent there usually correspond with a large amount of kilometres.

The biggest number of kilometres made by the truck also correspond to the location with the highest truck cost, the factory 1.

Is it important to remark the big number of kilograms of the collection points number 3 and 6, which correspond with the biggest trailer cost as it was expected by looking at Figure 11.

4.1.2. Not FTL container approach

For the approach where the trailer containers are not fully loaded when shipped, the results are going to be represented. As a resume, in this approach while the cost per load of the trailer is the 22,5 % than in the FTL approach, the utilization factor of the trailer is equal to 6.25%,so the results in this section are expected to be different from the previous one.

In the table below, the results obtained of the cost are shown, divided into the set-up cost, transport cost of the truck and the trailer, and the total cost.

Table 14. Results of the cost from the model simulation for the not FTL approach.

		Transport			
Location	Set-up	Truck	Trailer	Total transport	TOTAL
1	0	187403.87	0	187403.87	187403.87
2	0	66036.76	0	66036.76	66036.76
3	5000	62462.96	100724.38	163187.34	168187.34
4	5000	71073.1	49619.28	120692.38	125692.38
5	5000	57497.27	24687.65	82184.92	87184.92
6	5000	61810.07	74731.37	136541.44	141541.44
Total	20000	506284.03	249762.68	756046.71	776046.71

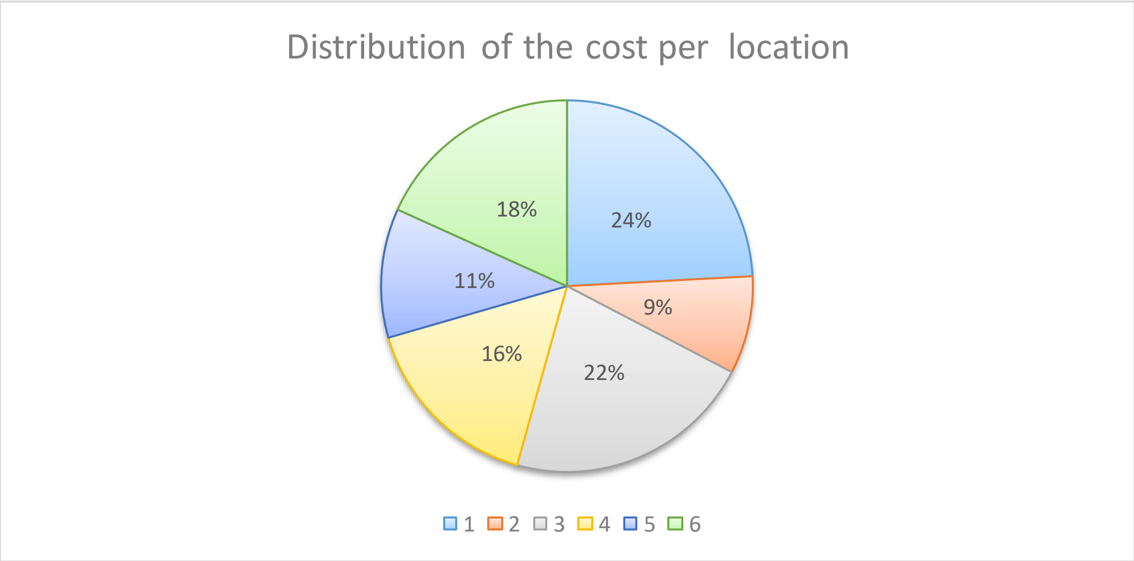


Figure 19. Distribution of the cost per location in terms of percentage.

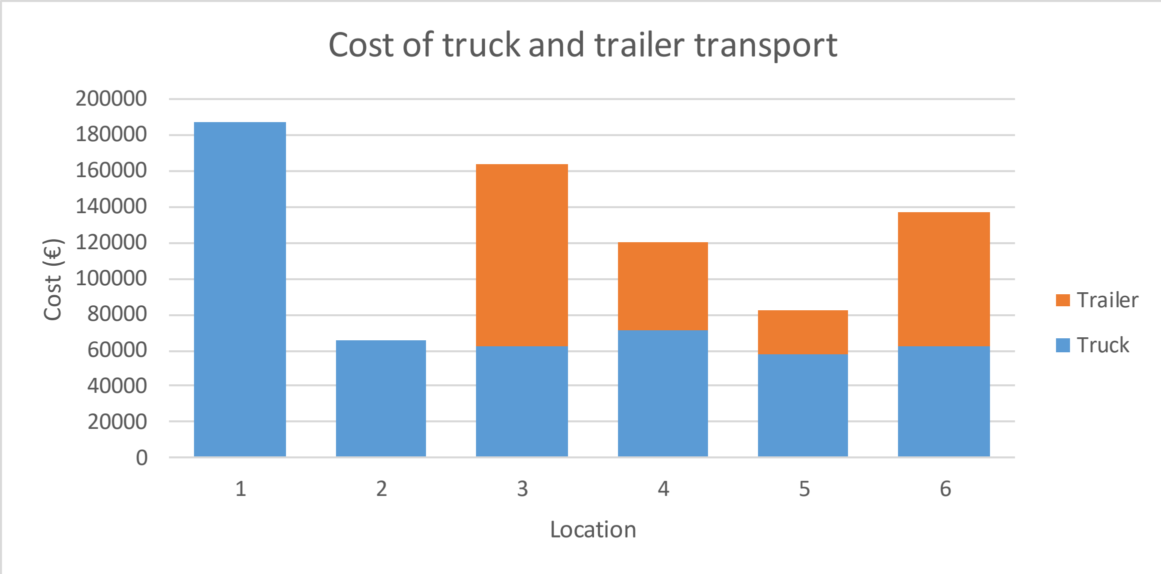


Figure 20. Distribution of transport cost per location in terms of percentage.

By comparing the cost of this approach with the one of the previous approach, the first conclusion is an overall increase of the total cost due to a big increase on both truck and trailer cost in each facility.

As in the example of the FTL approach, the transport cost related to factory 1 has the biggest influence on the total cost despite the fact of not having any set up or trailer cost associated with it.

As it can be seen if it is compared with the previous results, the factory 1 has an increase of the total cost influence of 3 %. In terms of total cost, it is remarkable the increase of the cost of the factory 1 on 80 000 € only in terms of truck cost, while in the other locations with the exception of factory 2 , where there was an small increase, the cost related with the truck diminishes,(in location 5 up to a 20 000 € reduction) but the trailer cost, since a bigger number of trailers has to be shipped out due to the low utilization of the trailer capacity, increase in much bigger terms, up to the point that in collection points 3 and 6 trailer costs are bigger than the truck cost, which means that this collection points carried out heavy orders.

Since the effect of the transport cost is the most influent factor, it can also be disaggregated in the two components that form the transport cost, the loading cost, and the distance cost. The results of the disaggregation can be seen in the next table:

Table. Distribution of Disaggregated Transport Cost in by location.

	Truck			Trailer		
Location	Load	Distance	Total	Load	Distance	Total
1	26878.7	160525	187403.7	0	0	0
2	5816.56	60220.2	66036.8	0	0	0
3	25286.8	37176.2	62463.0	6246.57	94477.81	100724.38
4	19653.9	51419.2	71073.1	3682.19	45937.09	49619.28
5	8816.69	48680.6	57497.3	2168.86	22517.79	24686.65
6	14939.4	46870.7	61810.1	5448.13	69283.24	74731.37
Total	101392.05	404891.9	506284.0	17545.75	232215.93	249761.68

As it was said previously, the increase on the trailer cost in the distance and loading cost, in the approach of not FTL, are around 220 000€ in comparison with the other approach.

Regarding to the truck cost, the most notably increment is on the factory 1 and also in factory 2, while in all collection points the cost of the truck are lower than in the previous approach.

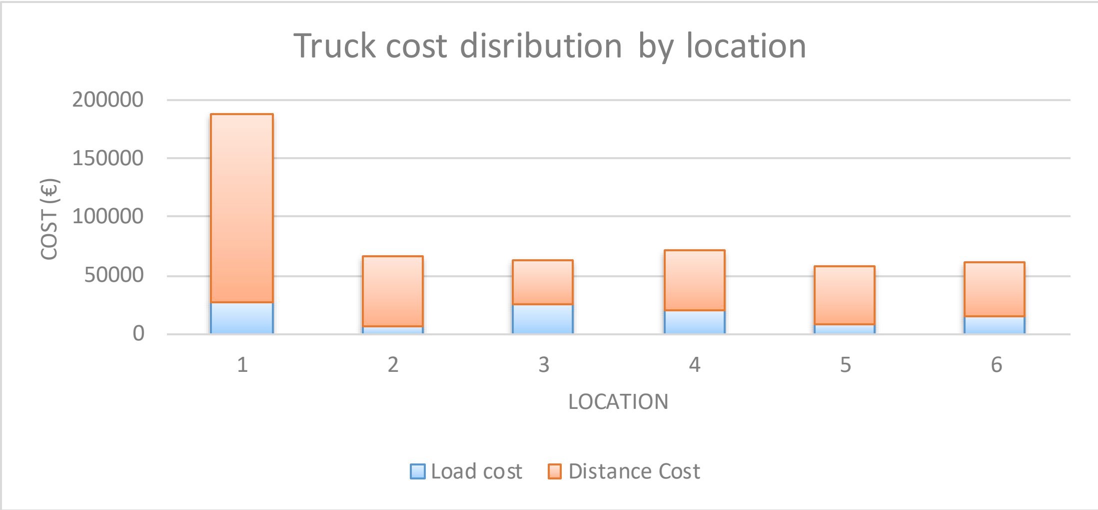


Figure 21. Truck cost distribution by location.

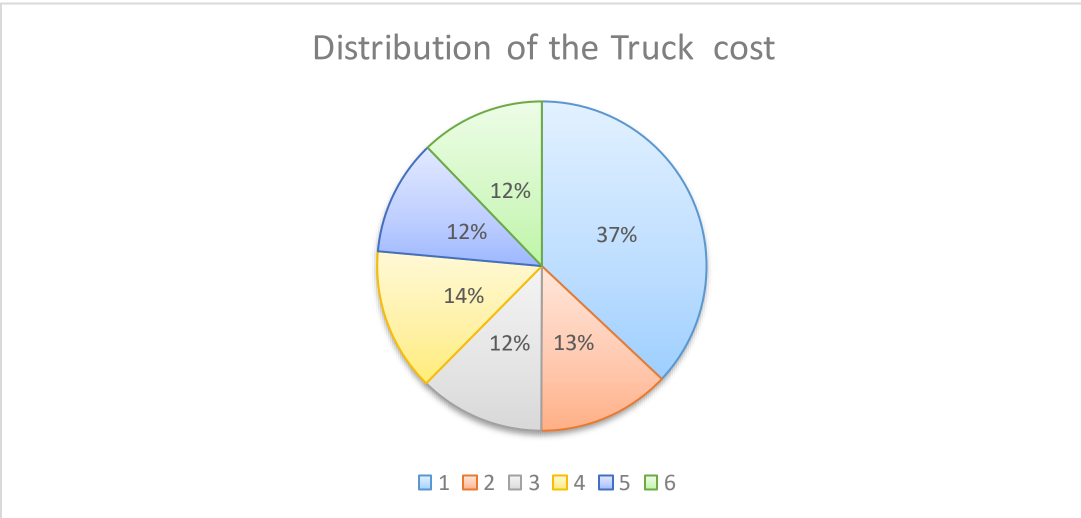


Figure 22. Distribution of total truck cost by location.

The same analysis is done with the trailer cost, and the results obtained are represented below.

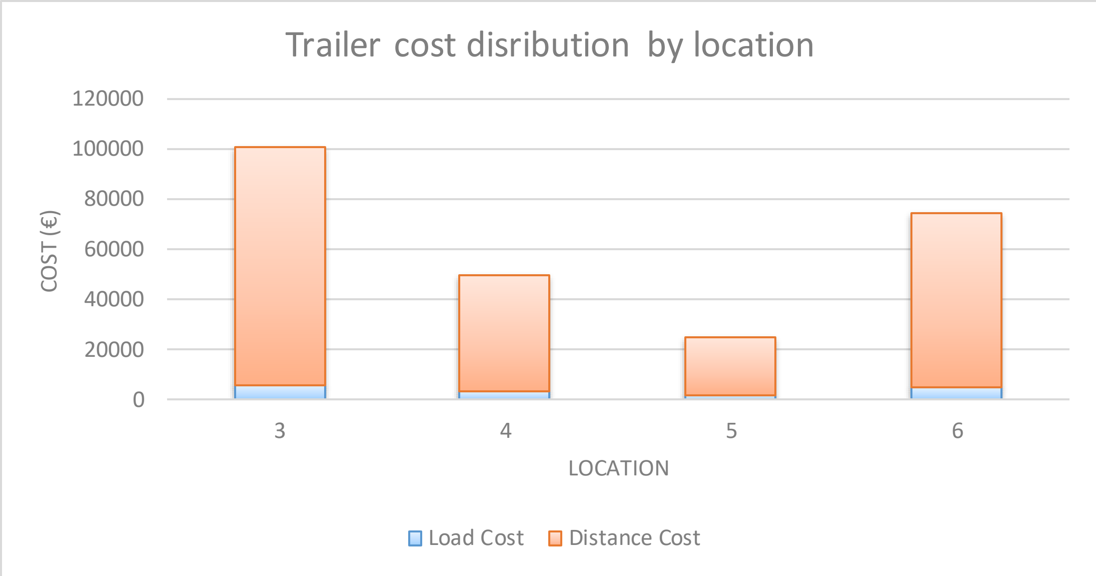


Figure 23. Trailer cost distribution by location.

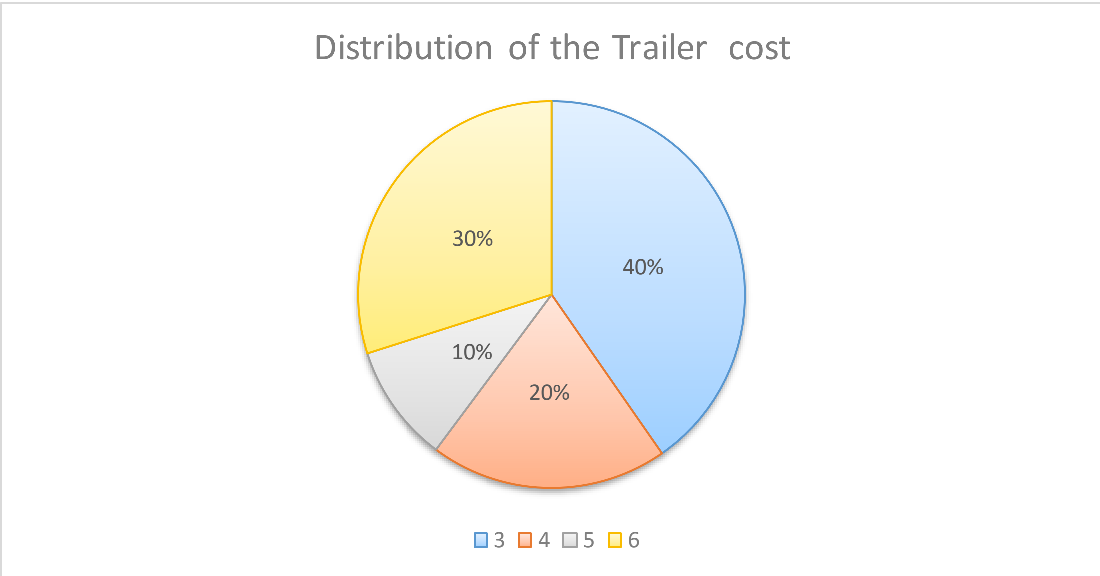


Figure 24. Trailer cost distribution by location.

As it was previously said, the trailer cost now by both, the load and distance cost ,has a huge increase which reflects into a big impact on the total cost, especially in the collection point 3, where in the previous approach ,the trailer associated cost of 8000 € is much more smaller than the 100000 € of the current approach.

The impact of the distance and load cost in the total transport cost is resumed in the table below, in terms of percentages.

Table 15. Impact of loading and distance in the total transport cost for trucks and trailer by location in terms of percentages.

	Truck			Trailer		
Location	**Load**	**Distance**	**Total**	**Load**	**Distance**	**Total**
1	3.56%	21.23%	24.79%			
2	0.77%	7.97%	8.73%			
3	3.34%	4.92%	8.26%	0.83%	12.50%	13.32%
4	2.60%	6.80%	9.40%	0.49%	6.08%	6.56%
5	1.17%	6.44%	7.61%	0.29%	2.98%	3.27%
6	1.98%	6.20%	8.18%	0.72%	9.16%	9.88%
TOTAL	13.41%	53.55%	66.96%	2.32%	30.71%	33.04%

By comparing the results with the ones obtained on the previous approach, it is remarkable how the impact of the total truck cost is reduced from a value of 94 % to a new one of 66 %, while the total trailer cost increases from the 5 % to a 33 % one. Regarding to each impact individually of each location, the total impact of factory 1 increases to almost 25 % from the previous 21%, where there is an increase of the distance cost but a decrease of the load. This could be explained on the average increase of kilometres done by the factory 1. In case of the trailer cost, the 10 points increase of the collection point 3, and the 8 points increase of the collection point 6, contribute to increase the overall impact of the trailer cost to the total transport cost in this approach.

In addition to the cost, other variables like the number of orders, total kilometres or weight managed by each location can also be studied in this approach as it is shown in the table below:

Figure 25 Distribution of orders, kilometres and weight in the locations

		Nº Kilometres			Weight(kg)		
Location	Nº of Orders	Truck	Trailer	Total	Truck	Trailer	Total
1	439	84580.44		84580.44	140800		140800
2	95	31729.91		31729.91	19550		19550
3	413	19588.08	239427.47	259015.55	66500	66500	133000
4	321	27092.7	153496.41	180589.11	39200	39200	78400
5	144	25649.71	57278.55	82928.26	23100	23100	46200
6	244	24696.07	118933.93	143630	58000	58000	116000

In comparison with the previous results of the FTL approach, now the distribution of the orders changes to an increase in benefit of the factories, since now the trailer costs are much more influent due to the low utilization of the trailer's capacity, while there is a reduction in the number of the orders made by the collection points. This change in the distribution of the orders reflects ,on the one hand, into changes of the kilometres and total weight done by each location, with an overall increase of the number of total kilometres of the truck by 40 000 for factory 1 and 6 000 by factory 2.On the other hand, for the rest of the locations, the value diminishes, while the distance covered by the trailers also diminishes in all the collection points, and the same scheme happens with the weight distribution, where the reduction of the kilograms done by each collection point contrast with the increase of the trailer cost since now, by having a minor capacity, the required number of trailers increase.

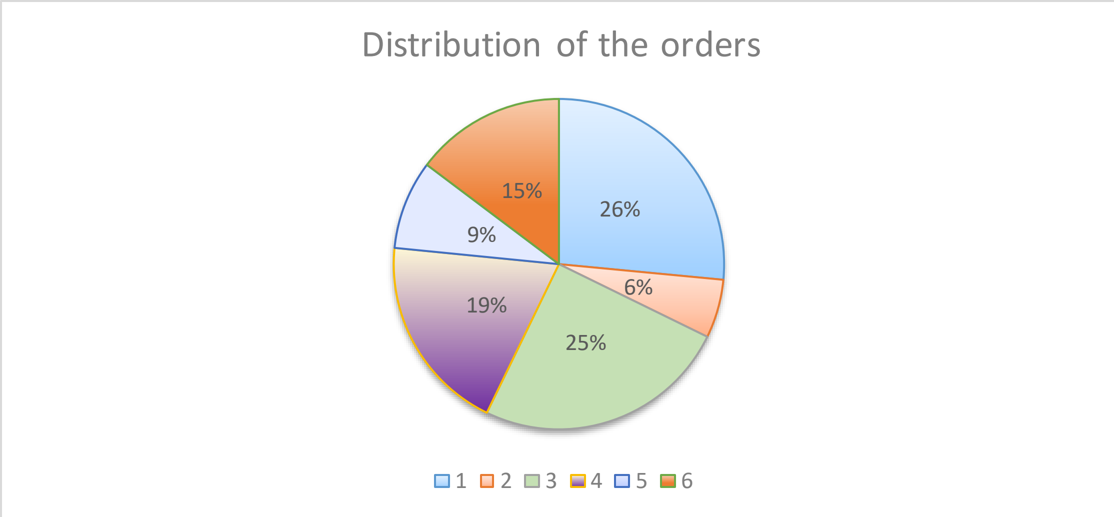


Figure 26. Distribution of the orders by location.

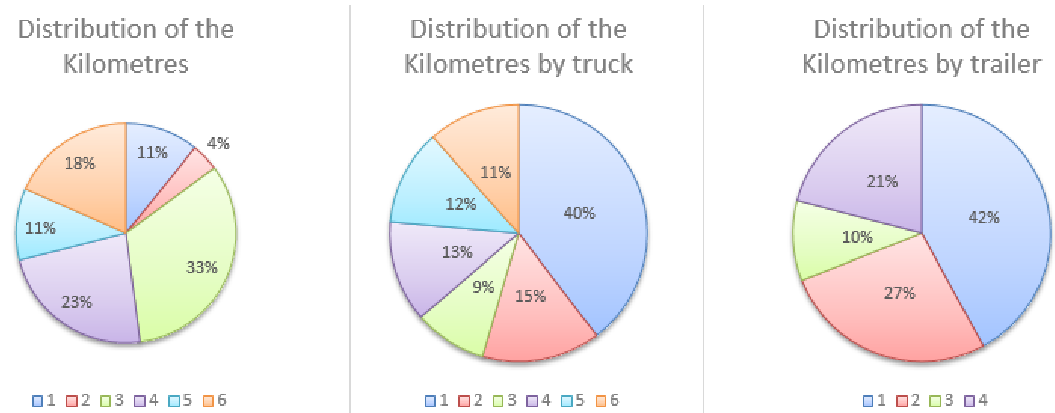


Figure 27. Distribution of kilometres by location, for total, truck and trailer.

While the distribution of the kilometres done by the trailer is really similar to the previous approach, the truck distribution changes completely, where factory 1 goes from a value of 24 % of the total truck kilometres up to a value of 40%. This increase contrast with the overall diminished of the kilometres made by the collection points.

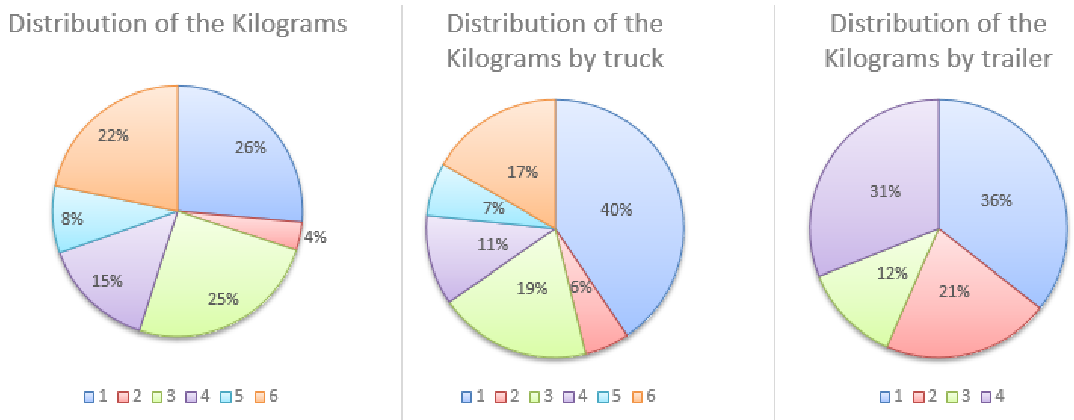


Figure 28. Distribution of kilograms by location, for total, truck and trailer.

The distribution of the kilograms also changes. From the truck side, the overall increase on factory 1 repeats again from a value of 25 to a new value of 40%. Regarding to the trailer, the distribution remains pretty much the same with minor's changes.

In the table below, it can be observed the difference on the number of trailers required depending of the approach taken:

Table 16. Number of trailers required.

	Number of trailers	
Collection point	FTL	Not FTL
3	7	83
4	4	53
5	4	31
6	7	78

Another indicator of the difference between one and other approach is the cost of order per location and in average, which can be seen in the following table:

Table 17. Cost per order for the different approaches.

	Cost per order	
Location	**FTL**	**Not FTL**
1	322.1186503	426.8880866
2	622.9009412	695.1237895
3	191.7529844	407.2332688
4	273.292362	391.5650467
5	452.0617742	605.4508333
6	318.2602465	580.0878689
TOTAL	306.5320411	468.6272403

As it can be observed, the cost per order decreases on the FTL approach for each one location and thus, the average. The cost per order is a good indicator of the performance since it allows have a quick view of the performance of the overall logistics network. It is remarkable the difference between the cost per order on the locations 3 and 6 in between both approaches. As it will be seen in next chapters, this is explained by the existence of overlapping areas, which is an indicator of a poor performance and thus worst results are expected.

4.2. Results in the map

The results obtained in the simulation can be processed into a text archive for a later representation on the *Google* application of *"My Maps"*. By doing this, it is possible to see the influence area of every distribution centre more easily.

Again, the results are going to be divided within the FTL approach or the not FTL one.

4.2.1. FTL approach

The results of the orders distribution within the location are represented in the following image:

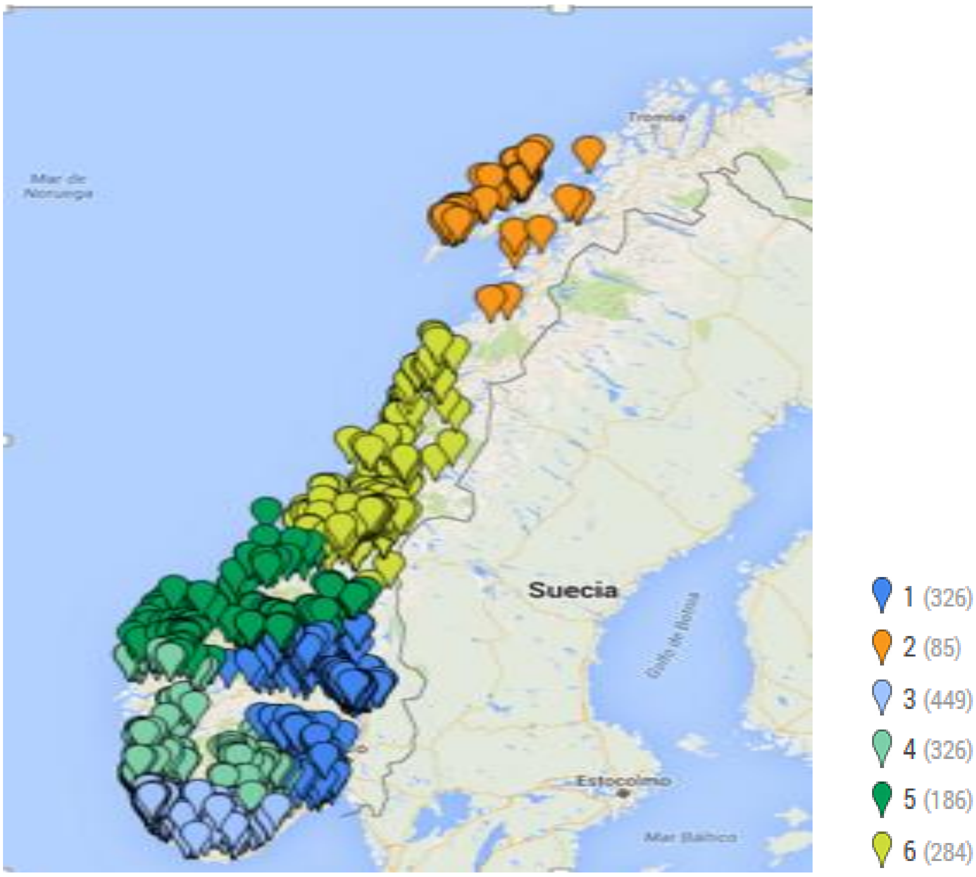


Figure 29. Distribution of the orders by location for the model for FTL approach.

In the image, all the orders are coloured whether they are assigned to the different locations, so the influenced area of the different collection points or the factories are defined and can be seen. By doing zoom, it can be appreciated what are the boundaries of the model solution for the different location points:

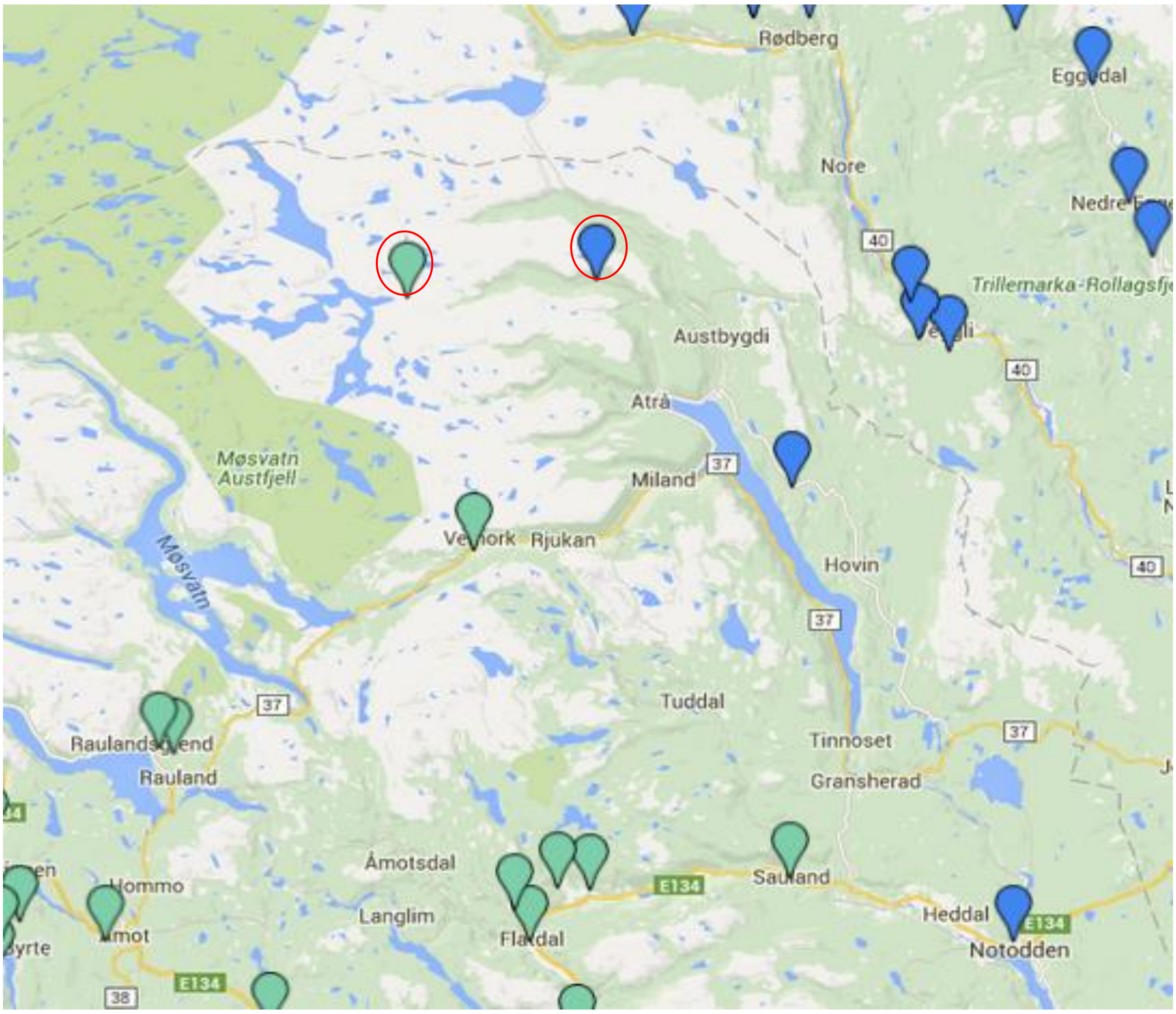


Figure 30. Boundaries of the model for FTL approach.

An analysis of the orders in the boundary can be done. The orders in the red circle are the number 625 (which is assigned to the location 4) and 623 (which is assigned to factory 1). The total cost of sending the order either to factory 1 or to collection point number 4 was calculated and expressed in the table below:

Table 18. Cost and distance of the orders in the boundary.

	Distance		COST	
Order	To Location 4	To Factory 1	To Location 4	To Factory 1
625	227.2032	252.0315	497.3560712	539.557584
623	248.43	232.3041	537.6424	502.116951

So, as it can be observed, the model has assigned the orders correctly. In this case, both orders had the same amount of weight of 50 kilograms.

As the analysis of the optimization results shows in the model under this approach, there are not existing overlapping areas on the different locations to where the orders are assigned. This is explained due to the low impact of the trailer cost, whereas trailer are loaded with full capacity, the impact of one single order, even if it is really heavy ,does not alter the boundaries and thus there are not overlapping areas.

The delimited area where one order is assigned to one facility or other are clearly visible in this approach , thus, the model can be solved in an analytical way for making a fast visualization table that can allow the user easily to decide where an order should be place. The table is represented below:

Table 19 . Distances of the orders by weight for the FTL approach.

Weight	From 4 to 1	From 3 to 1	From 5 to 1	From 6 to 1
50	2.59240105	3.00215372	2.26791638	2.62973509
100	5.18480209	6.00430745	4.53583275	5.25947017
150	7.77720314	9.00646117	6.80374913	7.88920526
200	10.3696042	12.0086149	9.07166551	10.5189403
250	12.9620052	15.0107686	11.3395819	13.1486754
300	15.5544063	18.0129223	13.6074983	15.7784105
350	18.1468073	21.0150761	15.8754146	18.4081456
400	20.7392084	24.0172298	18.143331	21.0378807
450	23.3316094	27.0193835	20.4112474	23.6676158
500	25.9240105	30.0215372	22.6791638	26.2973509
550	28.5164115	33.023691	24.9470801	28.927086
600	31.1088125	36.0258447	27.2149965	31.556821
650	33.7012136	39.0279984	29.4829129	34.1865561
700	36.2936146	42.0301521	31.7508293	36.8162912
750	38.8860157	45.0323059	34.0187456	39.4460263
800	41.4784167	48.0344596	36.286662	42.0757614
850	44.0708178	51.0366133	38.5545784	44.7054965
900	46.6632188	54.038767	40.8224948	47.3352316
950	49.2556199	57.0409208	43.0904112	49.9649667
1000	51.8480209	60.0430745	45.3583275	52.5947017

The table resumes what distance is worth it to take an order to one or other point depending on the weight of the order. The distance from the order to the factory 1 should be, at least, that distance plus the number reflected in the table according to the weight, so it will be worth to go to the collection point and later to the factory 1 by trailer instead of going to the factory 1 straight with the truck. This is because the impact of the trailer cost, as it was reflected in the distribution of the transport cost, it is quite small in comparison to the truck cost, so the effect of one single order on a trailer with 12 000 kilograms of capacity is quite small.

4.2.2. Not FTL approach

The results for the distribution of the orders among the different locations for the case of not FTL are represented in the following image:

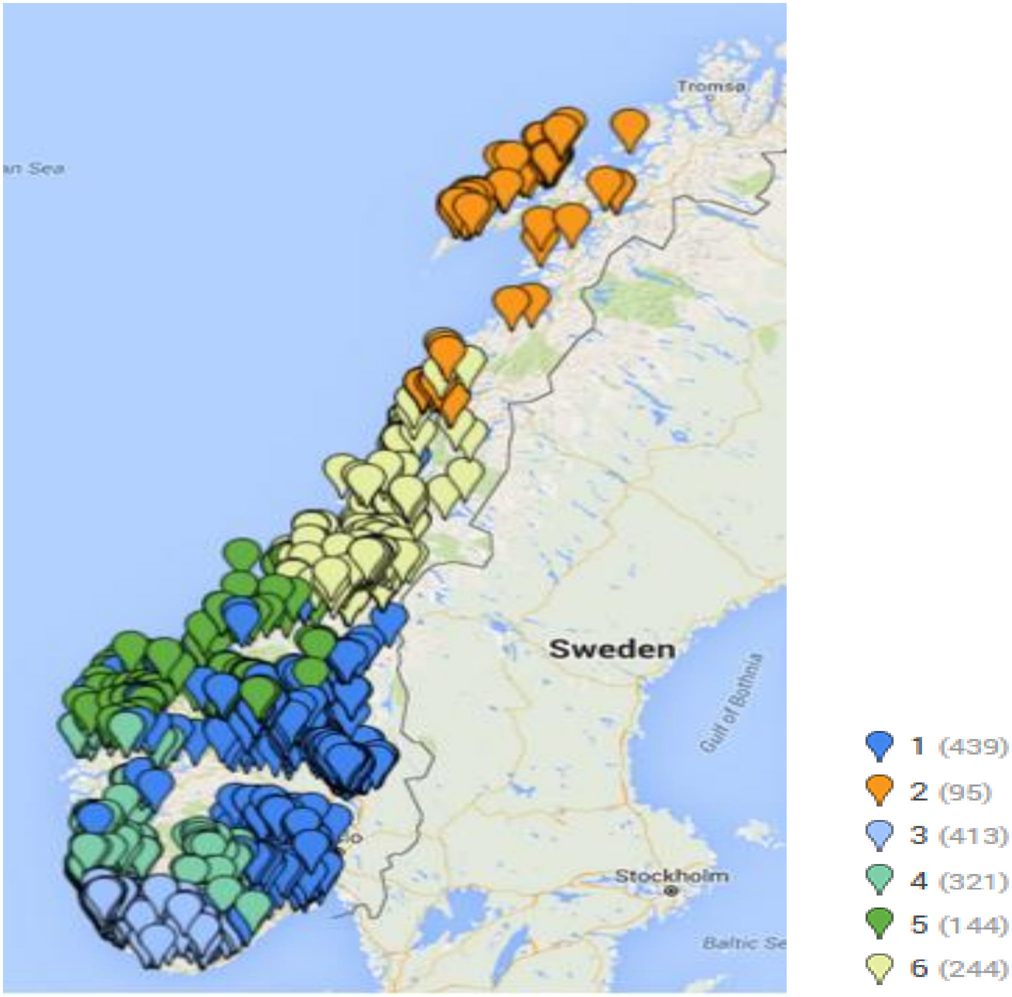


Figure 31. Distribution of the orders by location for the model for not FTL approach.

As it can be seen in this model, there are not clear boundaries for the different locations as it was in the previous approach since in this assumption, the influence on the weight is a critical factor and it is much bigger than in the FTL model, since now the trailer cost are more relevant than in the other approach. Now, the existence of overlapping areas are due to the high impact of the weight of the orders in the trailer cost since the capacity is reduced now. For a better understanding of the boundaries, it is possible to make zoom on them and study the distribution of the orders.

Figure 32. Boundaries of the model for the not FTL approach.

The analytical study of the cost of those orders in the red circle is going to be made. They are orders number 383 and 407, which were assigned to factory 1 and collection point 6 respectively. The analytical solution is represented in the following table:

Table 20. Cost and distance of the orders for not FTL approach.

		Distance		COST	
Order	weight(kg)	To Location 6	To Factory 1	To Location 6	To Factory 1
383	750	86.73	525.0672	1192.18568	1057.75204
407	250	87.00342	553.9842	548.4687	1112.63361

From the above results it can be concluded that the influence of the weight of the orders in this assumption is much bigger than in the previous one. As it was done before, the distribution of the orders with the weight is represented in the following table:

Table 21. Distances of the orders by weight for the not FTL approach.

Weight	From 4 to 1	From 3 to 1	From 5 to 1	From 6 to 1
50	33.3648877	39.9209306	28.173133	33.9622324
100	66.7297755	79.8418612	56.3462661	67.9244648
150	100.094663	119.762792	84.5193991	101.886697
200	133.459551	159.683722	112.692532	135.84893
250	166.824439	199.604653	140.865665	169.811162
300	200.189326	239.525584	169.038798	203.773394
350	233.554214	279.446514	197.211931	237.735627
400	266.919102	319.367445	225.385064	271.697859
450	300.28399	359.288375	253.558197	305.660092
500	333.648877	399.209306	281.73133	339.622324
550	367.013765	439.130237	309.904463	373.584556
600	400.378653	479.051167	338.077596	407.546789
650	433.743541	518.972098	366.250729	441.509021
700	467.108428	558.893028	394.423862	475.471254
750	500.473316	598.813959	422.596996	509.433486
800	533.838204	638.73489	450.770129	543.395719
850	567.203091	678.65582	478.943262	577.357951
900	600.567979	718.576751	507.116395	611.320183
950	633.932867	758.497681	535.289528	645.282416
1000	667.297755	798.418612	563.462661	679.244648

As it can be seen here, the influence of the weight of the order is much more influent in this case since the utilization factor used in this approach has very low numbers due to the small average capacity of the trailers. It is remarkable how the distance increases and thus the boundaries of the model with the weight of the order in comparison with the previous model. These results explain why in this approach, the factory 1 takes more orders, especially the heavy ones, since, as it can be seen by looking at the table, only distances bigger than 550 kilometres from factory 1 are worth it to send them to the collection points.

For an approximation, it is possible to calculate the distance that would be obtained by increase the capacity and thus performing with a utilization factor of 12 %, which means the average load of the trailers is 1500 kilograms but the same cost per load is maintained. It is expected that the contribution of the weight decreases and thus the boundaries would change, and also the distance for setting from which distance it is worth it to take an order to one factory or collection point.

Table 22. Distances of the orders by weight for the not FTL approach. (Utilization 12%).

Weight	From 4 to 1	From 3 to 1	From 5 to 1	From 6 to 1
50	16.6824439	19.9604653	14.0865665	16.9811162
100	33.3648877	39.9209306	28.173133	33.9622324
150	50.0473316	59.8813959	42.2596996	50.9433486
200	66.7297755	79.8418612	56.3462661	67.9244648
250	83.4122193	99.8023265	70.4328326	84.905581
300	100.094663	119.762792	84.5193991	101.886697
350	116.777107	139.723257	98.6059656	118.867813
400	133.459551	159.683722	112.692532	135.84893
450	150.141995	179.644188	126.779099	152.830046
500	166.824439	199.604653	140.865665	169.811162
550	183.506883	219.565118	154.952232	186.792278
600	200.189326	239.525584	169.038798	203.773394
650	216.87177	259.486049	183.125365	220.754511
700	233.554214	279.446514	197.211931	237.735627
750	250.236658	299.406979	211.298498	254.716743
800	266.919102	319.367445	225.385064	271.697859
850	283.601546	339.32791	239.471631	288.678975
900	300.28399	359.288375	253.558197	305.660092
950	316.966433	379.248841	267.644764	322.641208
1000	333.648877	399.209306	281.73133	339.622324

As it was expected, a reduction is achieved with a value of the double (which means that the boundaries of the model are now reduced) with the increase of the double utilization rate. The same analysis is done for the utilization factor of 25%, 50 % and 75 %.

Table 23. Distances of the orders by weight for the not FTL approach. (Utilization 25 %).

Weight	From 4 to 1	From 3 to 1	From 5 to 1	From 6 to 1
50	8.34122193	9.98023265	7.04328326	8.4905581
100	16.6824439	19.9604653	14.0865665	16.9811162
150	25.0236658	29.9406979	21.1298498	25.4716743
200	33.3648877	39.9209306	28.173133	33.9622324
250	41.7061097	49.9011632	35.2164163	42.4527905
300	50.0473316	59.8813959	42.2596996	50.9433486
350	58.3885535	69.8616285	49.3029828	59.4339067
400	66.7297755	79.8418612	56.3462661	67.9244648
450	75.0709974	89.8220938	63.3895493	76.4150229
500	83.4122193	99.8023265	70.4328326	84.905581
550	91.7534413	109.782559	77.4761158	93.3961391
600	100.094663	119.762792	84.5193991	101.886697
650	108.435885	129.743024	91.5626824	110.377255
700	116.777107	139.723257	98.6059656	118.867813
750	125.118329	149.70349	105.649249	127.358372
800	133.459551	159.683722	112.692532	135.84893
850	141.800773	169.663955	119.735815	144.339488
900	150.141995	179.644188	126.779099	152.830046
950	158.483217	189.62442	133.822382	161.320604
1000	166.824439	199.604653	140.865665	169.811162

Table 24. Distances of the orders by weight for the not FTL approach. (Utilization 50 %).

Weight	From 4 to 1	From 3 to 1	From 5 to 1	From 6 to 1
50	4.17061097	4.99011632	3.52164163	4.24527905
100	8.34122193	9.98023265	7.04328326	8.4905581
150	12.5118329	14.970349	10.5649249	12.7358372
200	16.6824439	19.9604653	14.0865665	16.9811162
250	20.8530548	24.9505816	17.6082081	21.2263953
300	25.0236658	29.9406979	21.1298498	25.4716743
350	29.1942768	34.9308143	24.6514914	29.7169534
400	33.3648877	39.9209306	28.173133	33.9622324
450	37.5354987	44.9110469	31.6947747	38.2075115
500	41.7061097	49.9011632	35.2164163	42.4527905
550	45.8767206	54.8912796	38.7380579	46.6980696
600	50.0473316	59.8813959	42.2596996	50.9433486
650	54.2179426	64.8715122	45.7813412	55.1886277
700	58.3885535	69.8616285	49.3029828	59.4339067
750	62.5591645	74.8517449	52.8246244	63.6791858
800	66.7297755	79.8418612	56.3462661	67.9244648
850	70.9003864	84.8319775	59.8679077	72.1697439
900	75.0709974	89.8220938	63.3895493	76.4150229
950	79.2416084	94.8122102	66.911191	80.660302
1000	83.4122193	99.8023265	70.4328326	84.905581

Table 25. Distances of the orders by weight for the not FTL approach. (Utilization 75 %).

Weight	From 4 to 1	From 3 to 1	From 5 to 1	From 6 to 1
50	2.78040731	3.32674422	2.34776109	2.83018603
100	5.56081462	6.65348843	4.69552217	5.66037207
150	8.34122193	9.98023265	7.04328326	8.4905581
200	11.1216292	13.3069769	9.39104434	11.3207441
250	13.9020366	16.6337211	11.7388054	14.1509302
300	16.6824439	19.9604653	14.0865665	16.9811162
350	19.4628512	23.2872095	16.4343276	19.8113022
400	22.2432585	26.6139537	18.7820887	22.6414883
450	25.0236658	29.9406979	21.1298498	25.4716743
500	27.8040731	33.2674422	23.4776109	28.3018603
550	30.5844804	36.5941864	25.8253719	31.1320464
600	33.3648877	39.9209306	28.173133	33.9622324
650	36.145295	43.2476748	30.5208941	36.7924184
700	38.9257024	46.574419	32.8686552	39.6226045
750	41.7061097	49.9011632	35.2164163	42.4527905
800	44.486517	53.2279075	37.5641774	45.2829765
850	47.2669243	56.5546517	39.9119385	48.1131626
900	50.0473316	59.8813959	42.2596996	50.9433486
950	52.8277389	63.2081401	44.6074606	53.7735346
1000	55.6081462	66.5348843	46.9552217	56.6037207

It is remarkable how, while approaching the utilization rate of 100% which will mean having and average capacity of the trailers of 12 000 kilograms, the distances tend to equal to the approach of FTL.

By taking into consideration all the above results, it can be concluded that the increase of the utilisation factor of the trailer average capacity is a key factor if the same cost per load is maintained, since as it was seen in the tables above, it diminish the impact of the trailer cost when it is enhanced by reducing the distances from where to take the order and thus changing the boundaries.

4.3. Additional collection point.

As the set up costs in this particular case are really low in comparison with the transport cost, it is interesting to see the effect of locating a new collection point in the cost of the model. For analysing this, the center of gravity method and the Weber method are going to be studied in order to select the best location that can minimize the total cost.

The selection of the factor that will influence more the location of a new collection point is an important decision since usually location of warehouses are part of the strategic decision planning and thus, they are decisions made for a long-term frame of time and are really expense to reverse in case they are not meeting the criteria as it was expected. For this reason, it is worth too see the influence of locating the new collection point in the different locations attending to the factors and see which factor is more important to achieve a reduction of the total cost, which is the main objective of setting a new collection point.

Again, the two different approaches are going to be study.

4.3.1. FTL approach.

It can be seen in the table below the possible different locations for the new collection point attending to the different criteria (number of orders, total weight, number of kilometres and total cost by each location) by the use of the center of gravity method. It is important to remark that the weight and the kilometres were only taken into account those made by the truck but not the trailer, since is influence is not as strong as the truck cost and thus lead to worse results in terms of optimization.

Table 26. Location of new collection point by different factors using centre of gravity.

Location	X	Y	Orders	Weight	Kilometres	Cost
1	60.8323	11.09972	326	85150	44813.04	105010.68
2	69.24081	19.23436	85	14300	25155.32	52946.58
3	58.63039	5.599	449	78700	23519.6	86097.09
4	59.53082	5.84245	326	43150	31554.48	89093.31
5	62.98124	8.65731	186	42250	33752.12	84083.49
6	63.81768	11.00581	284	83600	31430.81	90385.91
		X	61.1640235	61.4981879	62.3306668	61.9949822
		Y	8.70044005	9.21443925	10.1743762	9.67120871

For a first approach, the average of all the possible locations was selected. This mean that the additional collection point it is located in (61.74, 9.44).

4.3.1.1. Results of model with new collection point using average

Following the same procedure as in the previous section, it is possible to calculate the new cost distribution with the solution of the software and using the model.

The results in terms of set up cost, transport cost (truck and trailer) and total cost are represented below.

Table 27 Cost with a new collection point using average for gravity centre method.

Cost	Set-up	Truck	Trailer	Total transport	TOTAL
TOTAL(€)	**25000**	**432060.047**	**25256.875**	**457316.922**	**482316.923**
% Δ	**25%**	**-6.566%**	**0.240%**	**-6.214%**	**-4.98%**

As it can be observed, while an increment of a 25 % on the set-up cost, a reduction of a 6.214 % of the total transport cost is achieved, which gives a total 4.98 % percent of saving in the total cost.

4.3.1.2. Results of model with new collection point using average without Factory 2.

The same analysis as in the model with the addition of the new collection point in the average location is going to be made, but in this case, the data from factory 2 are not going to be taken into account. The reason for doing this, is that the factory 2 itself behaves almost like a single model because of the long distance between it and the collection points.

Table 28. Possible locations by different factors without factory 2 using CoG method.

	X	Y	Orders	Weight	Km	Cost
1	60.8323	11.09972	326	85150	44813.04	105010.68
3	58.63039	5.599	449	78700	23519.6	86097.09
4	59.53082	5.84245	326	43150	31554.48	89093.31
5	62.98124	8.65731	186	42250	33752.12	84083.49
6	63.81768	11.00581	284	83600	31430.81	90385.91
		X	60.7270235	61.1655471	61.2776178	61.1512023
		Y	8.1304953	8.78396046	8.79370908	8.55757548

As it can be noticed, the possible location of the new collection point depending of the factor considered changes if Factory 2 is not take into account. Using the average method as it was used previously, the location of the collection point is (61.08, 8.56)

The results obtained locating the collection point in that coordinates are represented below.

Table 29. Cost with a new collection point using average for gravity centre method without factory 2.

Cost	Set-up	Truck	Trailer	Total transport	TOTAL
TOTAL(€)	25000	440875.925	25419.195	466295.12	491295.12
% Δ	0.25	-4.659%	0.884%	-4.373%	-3.22%

As it can be seen, the total cost is bigger than using the average with all the factories, so in next analysis, the data from factory 2 are going to be taken into account.

4.3.1.3. Results of model with new collection point using weight as factor

The new collection point is going to be located at the coordinates given by using the gravity centre method using the factor of the weight, as it can be seen in table 26. The results of placing the collection point at that location (61.49818794, 9.214439254) are show in the table below.

Table 30. Cost with a new collection point using weight as factor for CoG method.

Cost	Set-up	Truck	Trailer	Total transport	TOTAL
TOTAL(€)	25000	433546.684	25186.094	458732.778	483732.778
% Δ	25%	-6.244%	-0.041%	-5.924%	-4.71%

The results using the weight factor are worse of those using the average method in terms of total cost, while the trailer cost are less.

The use of the Weber method using weight as criteria for reduction, was performance using the *Solver* tool from Excel and establishing the total weighted distance as objective function to minimize while the decisions variables are the coordinates of the new collection point. By doing this, it is expected to obtain the coordinates that achieve the biggest reduction on the weighted distance.

Table 31. Location of the new collection point using Weight as factor with the Weber method.

Location	X	Y	Weight	Distance	Weighted Distance
1	60.8323	11.09972	85150	1.64088154	139721.0631
2	69.24081	19.23436	14300	12.15650307	173837.994
3	58.63039	5.599	78700	5.12222495	403119.1036
4	59.53082	5.84245	43150	4.426122293	190987.177
5	62.98124	8.65731	42250	1.658432055	70068.75431
6	63.81768	11.00581	83600	2.490646293	208218.0301
TOTAL	61.695	9.704	347150	F.O	1,185,952

As it can be seen, the results of the coordinates using the Weber method are really similar to the ones using the centre of gravity but not the same. The results in terms of cost of the coordinates obtained by the Weber method are represented in the table below.

Table 32. Cost with a new collection point using weight as factor for weber method

Cost	Set-up	Truck	Trailer	Total transport	TOTAL
TOTAL(€)	25000	434443.289	25260.325	459703.614	484703.614
% Δ	25%	-6.050%	0.254%	-5.724%	-4.51%

As it can be observed, the results obtained are worse that by using the coordinates of the center of gravity method.

4.3.1.4. Results of model with new collection point using cost as factor

Now, the cost is the factor that is going to be used in the gravity centre method. The location thus is going to be (61.99498217, 9.671208711), as it can be seen in the table 26.The results of the model are shown in the following table:

Table 33. Cost with a new collection point using cost as factor for CoG method.

Cost	Set-up	Truck	Trailer	Total transport	TOTAL
TOTAL(€)	25000	436583.694	25338.964	461922.658	486922.658
% Δ	25%	-5.587%	0.566%	-5.269%	-4.08%

Again, the results are worse than by using the average and also than by using the cost as factor, and also worse than by using weight as a factor.

With the use of the Weber method, the coordinates obtained are represented in the table below.

Table 34. Location of the new collection point using cost as factor with the Weber method.

Location	X	Y	Cost	Distance	Weighted Distance
1	60.8323	11.09972	105010.68	2.046771184	214932.8338
2	69.24081	19.23436	52946.58	12.2128136	646626.7125
3	58.63039	5.599	86097.09	5.077742784	437178.8774
4	59.53082	5.84245	89093.31	4.33061386	385828.7231
5	62.98124	8.65731	84083.49	1.247049736	104856.294
6	63.81768	11.00581	90385.91	2.429267931	219571.5926
TOTAL	61.987	9.409	507617.06	F.O	2,008,995

And the total cost of the model by placing the new collection point on those coordinates is:

Table 35. Cost with a new collection point using cost as factor for weber method

Cost	Set-up	Truck	Trailer	Total transport	TOTAL
TOTAL(€)	25000	433675.436	25295.903	458971.339	483971.339
% Δ	25%	-6.216%	0.395%	-5.875%	-4.66%

In this case, the results obtained are better than the one using the centre of gravity method.

4.3.1.5. Results of model with new collection point using distance as factor

Now, the distance factor is going to be used in the gravity centre method. The location thus is going to be (62.3263, 10.1474), as it can be seen in the table 26, and the solution obtained is much worse than the previous one.

Table 36. Cost with a new collection point using distance as factor for CoG method.

Cost	Set-up	Truck	Trailer	Total transport	TOTAL
TOTAL(€)	25000	446829.171	25357.085	472186.256	497186.256
% Δ	25%	-3.372%	0.638%	-3.165%	-2.05%

The results of the coordinates obtained using the Weber method are:

Table 37. Location of the new collection point using distance as factor with the Weber method

Location	X	Y	km	Distance	Weighted Distance
1	**60.8323**	**11.09972**	44813.04	1.80047163	80684.60717
2	**69.24081**	**19.23436**	25155.32	11.87309896	298671.6038
3	**58.63039**	**5.599**	23519.6	5.406691343	127163.2177
4	**59.53082**	**5.84245**	31554.48	4.67912492	147647.3537
5	**62.98124**	**8.65731**	33752.12	1.454199289	49082.30891
6	**63.81768**	**11.00581**	31430.81	2.144442316	67401.55899
TOTAL	62.058	9.781	190225.37	F.O	770,651

And the total cost associated to locate the new collection point in that coordinates is represented in the following table.

Table 38. Cost with a new collection point using distance as factor for weber method

Cost	Set-up	Truck	Trailer	Total transport	TOTAL
TOTAL(€)	25000	438722.683	25359.298	464081.981	489081.981
% Δ	25%	-5.125%	0.646%	-4.827%	-3.65%

Which in this case, it shows a much better performance that the one using the CoG method in the same factor.

4.3.1.6. Results of model with new collection point using orders as factor

The same procedure as before is going to be used. The location of the new collection point attending to the data of table 26 based on the orders is (61.1624, 8.7). The results are better than by using distance, but not better than the previous approaches.

Table 39. Cost with a new collection point using orders as factor for gravity centre method.

Cost	Set-up	Truck	Trailer	Total transport	TOTAL
TOTAL(€)	25000	439471.829	25349.997	464821.826	489821.826
% Δ	25%	-4.963%	0.610%	-4.675%	-3.5056%

Finally, the weber method was employed to obtain the coordinates by using orders as factors, the coordinates can be seen below.

Table 40. Location of the new collection point using orders as factor with the Weber method

Location	X	Y	Orders	Distance	Weighted Distance
1	60.8323	11.09972	326	2.947227549	960.7961811
2	69.24081	19.23436	85	13.93942962	1184.851518
3	58.63039	5.599	449	3.341057673	1500.134895
4	59.53082	5.84245	326	2.628668928	856.9460706
5	62.98124	8.65731	186	2.253871566	419.2201114
6	63.81768	11.00581	284	4.164029955	1182.584507
TOTAL	60.785	8.153	1656	F.O	6,105

And the results of the cost by using those coordinates for the emplacement of the new collection point are also represented in the following table.

Table 41 Cost with a new collection point using orders as factor for weber method

Cost	Set-up	Truck	Trailer	Total transport	TOTAL
TOTAL(€)	25000	444596.998	25365.85	469962.848	494962.848
% Δ	25%	-3.854%	0.672%	-3.621%	-2.4929%

Which, as it can be analysed, turns into worse results than the use of the center of gravity method with the same factor.

4.3.1.7. Results of model with new collection point using an average-pondered as factor

As it was seen, the best reduction was obtained by using the average one. By analysing what the cost was by using each factor individually, it was observed that the weight is the factor which achieves more savings, despite the fact all the possible new locations are placed in similar points, the cost is quite different.

In order to achieve a better location of the collection point, an average-pondered approach is going to be used. As it was mentioned, not all the factors achieve the same value, so the pondered was made in order to achieve the maximum savings of total cost. The results and criteria for pondering each factor is shown in table below:

Table 42. Value of pondering factors for average with the CoG data.

Factor	Total Cost	% of Total	
Currently	507617.06		**Pondered**
Weight	483732.778	4.7025%	**0.284810303**
Cost	486922.658	4.0768%	**0.246772288**
Orders	489809.287	3.5081%	**0.212350416**
Km	496963.573	2.0987%	**0.127038479**

So the location of the new collection point using the pondered values is (61.748; 9.4494).The results obtained are represented in the following table.

Table 43. Cost with a new collection point using average-pondered as factor for gravity centre method.

Cost	Set-up	Truck	Trailer	Total transport	TOTAL
TOTAL(€)	25000	432135.423	25264.527	457399.95	482399.95
% Δ	25%	-6.549%	0.270%	-6.197%	-4.968%

In this case, the best performance was obtained using just the simple average (the location obtained it is quite similar to the one using factors, with a barely 0, 5 kilometres difference between them) so the location selected for the new collection point would be defined by just using the average method.

A different approach can be taken by using a combination of the both methods (CoG and Weber) but taking the results with the best performance on each factor. This was done and the results of the pondered factors are shown in the table below.

Table 44. Value of pondering factors for average with the CoG and Weber data.

Factor	Total Cost	% of Total	
Actual	507617.06		Pondered
Weight	483732.778	4.7052%	0.2848103
Cost	483971.339	4.6582%	0.28196556
Orders	489821.826	3.5056%	0.21220089
Km	489081.981	3.6514%	0.22102324
		0.1652039	

And the location using this factors is (61.75, 9.443), which is really similar to the one calculated with just the CoG data. The results in terms on cost of using this coordinates are represented in the table below.

Table 45. Cost with a new collection point using average-pondered as factor for CoG and Weber.

Cost	Set-up	Truck	Trailer	Total transport	TOTAL
TOTAL(€)	25000	432089.577	25260.258	457349.835	482349.835
% Δ	25%	-6.559%	0.253%	-6.207%	-4.978%

As it can be observed, the results are better than just using the coordinates obtained from the CoG method, but still worse that just by using the average. For this reason, the Weber method is not going to be employed in the approach of not FTL since, as it was seen in this section, it does not lead to achieve an optimization of the emplacement of the new collection point.

4.3.1.8.. Results of model with two new collection points using average as factor

In case a second one collection point was required, the same process followed as before can be done to determine the best location.

The results obtained for the average as gravity centre factor by each facility are represented in the table below, where it is possible to see the locations of the second additional collection point.

Table 46. Location of second new collection point by different factors.

	X	Y	Orders	Weight	Km	Cost
1	60.8323	11.09972	247	68750	31701.57	75289.47
2	69.24081	19.23436	85	14300	25155.32	52946.58
3	58.63039	5.599	449	78700	23519.6	28519.6
4	59.53082	5.84245	310	42000	26622.54	31622.54
5	62.98124	8.65731	64	16900	8093.33	13093.33
6	63.81768	11.00581	283	83350	31228.97	36228.97
7	61.7482118	9.44946884	218	43150	27943.97	32943.97
		X	61.0444013	61.4572728	62.4431686	62.841308
		Y	8.6024854	9.20515247	10.5023561	11.4034352

The location selected was the average one since it gave the best results in the previous section, the location of the second additional collection point thus is: (61.94653767, 9.928357294). Since this location is quite similar to the previous location point, it is not expected to have a big reduction of the transport cost as it was achieved with the first one. Since the reduction is not going to be bigger than the set up cost, the software solution results into not open the new location point, as it can be seen in the following image. Note that facilities in this case make references to locations.

```
------------------------------
 Number of facilities opened 7
Where:
 Facility 1 is opened: 1
 Facility 2 is opened: 1
 Facility 3 is opened: 1
 Facility 4 is opened: 1
 Facility 5 is opened: 1
 Facility 6 is opened: 1
 Facility 7 is opened: 1
 Facility 8 is opened: 0
------------------------------
```

Figure 33. Solution for the model with two additional collection points.

Only if the minimum number of facilities opened (parameter a in the model) is turned into 8, the software would opened the new location point since it is forced to open the facility. By doing this, the cost solution of the model adding two additional collection point is represented in the table below:

Table 47. Cost with two new collection point using average as factor for gravity centre method.

Cost	Set-up	Truck	Trailer	Total transport	TOTAL
TOTAL(€)	30000	429163.986	25257.492	454421.478	484421.478
% Δ	50%	-7.192%	0.242%	-6.808%	-4.570%

This results obtained are interesting to comment. As it was expected, the total transport cost is less that by adding a single collection point, where the truck cost is less but the trailer cost is slight bigger. However, since the difference is less than the cost of set up of the additional collection point, the total cost is bigger than only adding one collection point. So attending to the results above, it can be concluded that for this problem, the optimal number of collection points is 7 instead of 8, as it is the number that achieves the minimum cost.

The study of the total cost by number of collection points is made divided then into the set up cost, the transport cost and the total cost, as they will behave differently when the number of the collection points varies.

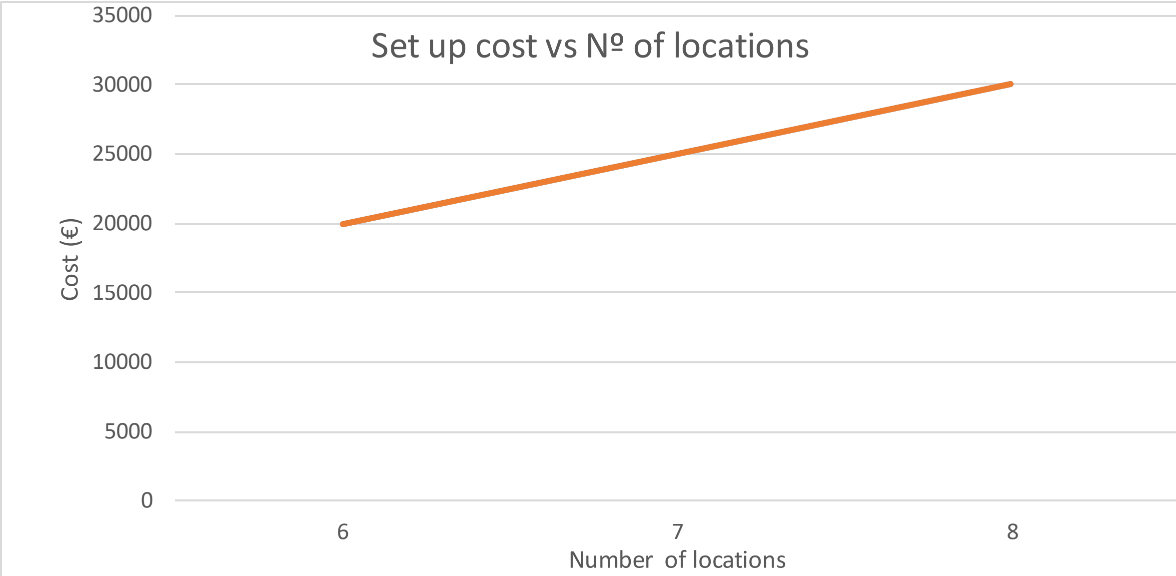


Figure 34. Set up cost vs number of locations.

The set up cost increases as the number of the locations increase, since this value depends on the number of collection points.

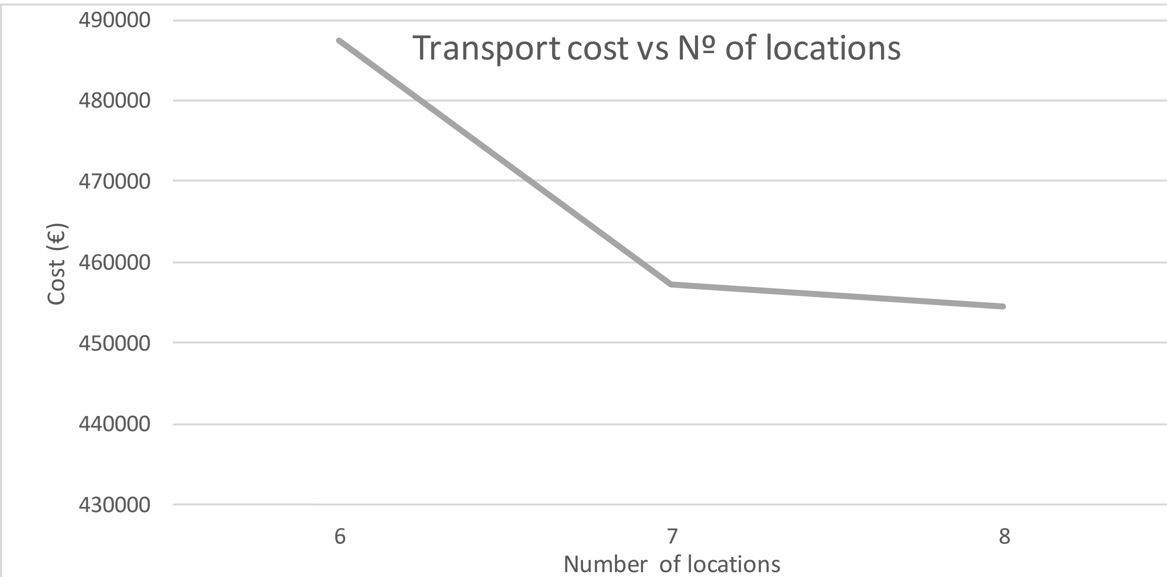


Figure 35. Transport cost vs number of locations.

The transport cost suffers a big reduction with the addition of the new collection point, where the slope is strong, but by opening of successive collection points, the transport cost continues to diminish but at a slower rate, which will lead to influence the total cost. From this graphic, it could be expected that the optimal number of locations for this problem is seven, and the results should coincide with the total costs.

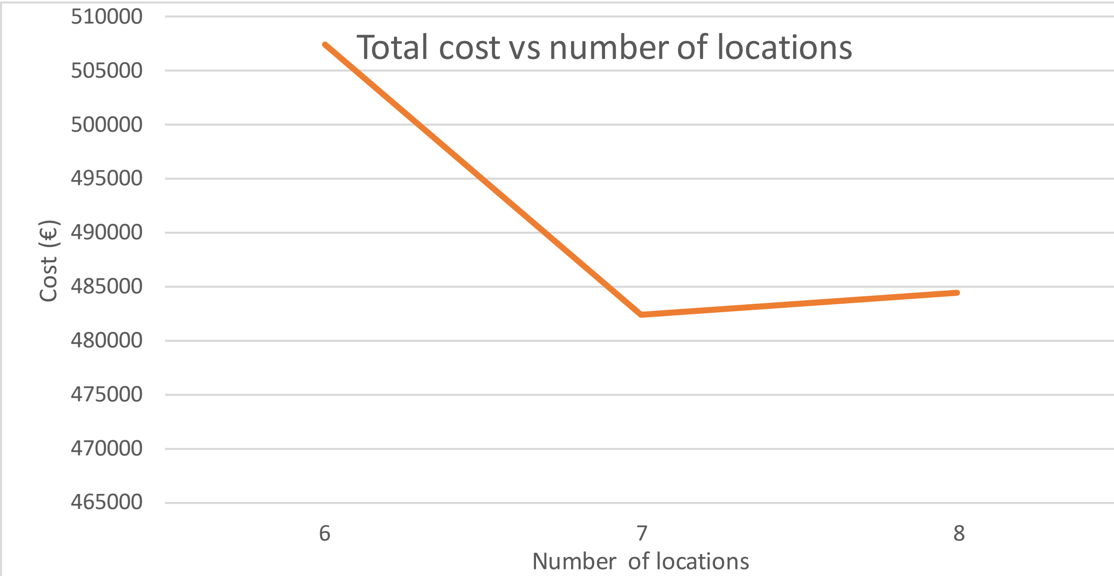


Figure 36. Total cost vs number of locations.

As it was said before, the increase on the total cost after achieving a minimum represents the fact that adding the second additional collection point turns into be more expensive than the potential savings in transport that second collection point could achieve. This was the expected behaviour of the total cost since as it is described in the theory, it always achieves a minimum followed by an increase. The optimal number of locations is the one who achieves the minimum value of the total cost, since it would lead to the optimization, and in this case, as it was described by analysing the total transport cost, it is seven.

4.3.1.9. Results of the model for the optimal solution

As it was previously showed in the above chapters, the optimal solution for this case was the one where an additional collection point was opened. For this reason, the results of the optimal solution are going to be studied.

The location of the map of the new collection centre is shown in the following image:

Figure 37. Location of the collection points and factories.

It is also important to check if it is feasible the construction of a new collection point in that place; this means that the optimal solutions does not contemplate if the optimal location of the collection point is going to be placed in a mountain or in some place where is not possible to build. Unfortunately, in this case, the additional collection point was placed in a mountain, so it has to be moved some kilometres to the right side, where there as a road and some potential places to locate the new collection point, which are marked by the red rectangle in the image below.

Figure 38. Possible optimal location for the new collection point.

It is also possible to measure the distance to the factory number 1, so it is possible to estimate if it is a good possible location of the factories since it should have a good road transport with the factory number 1 since the traffic with the trailer is expected to be important.

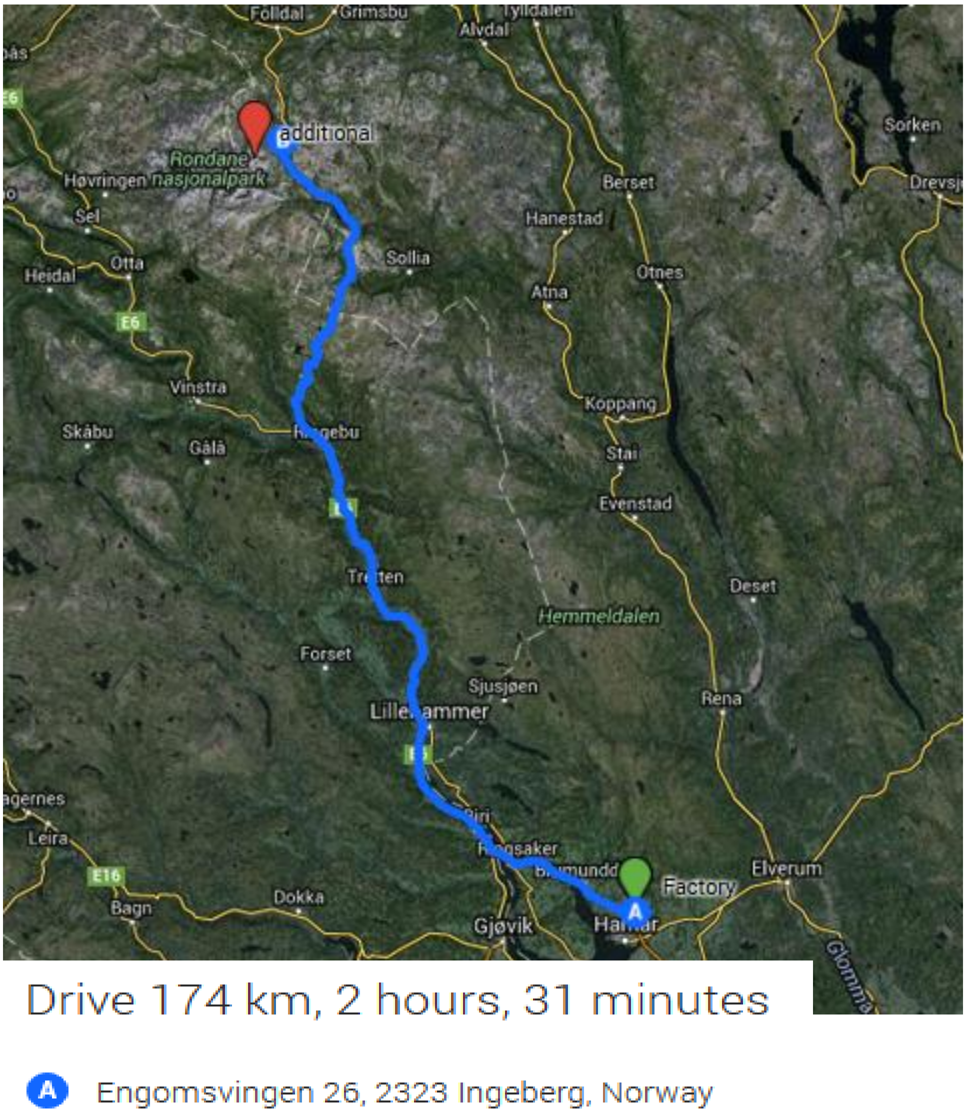


Figure 39. Distance to Factory 1 of the new collection point.

As it can be seen, the new collection point would be allocated in a good place near the road, and it will take about 174 kilometres of driving for the trailers.

The distribution of the orders with this new collection point was analysed.

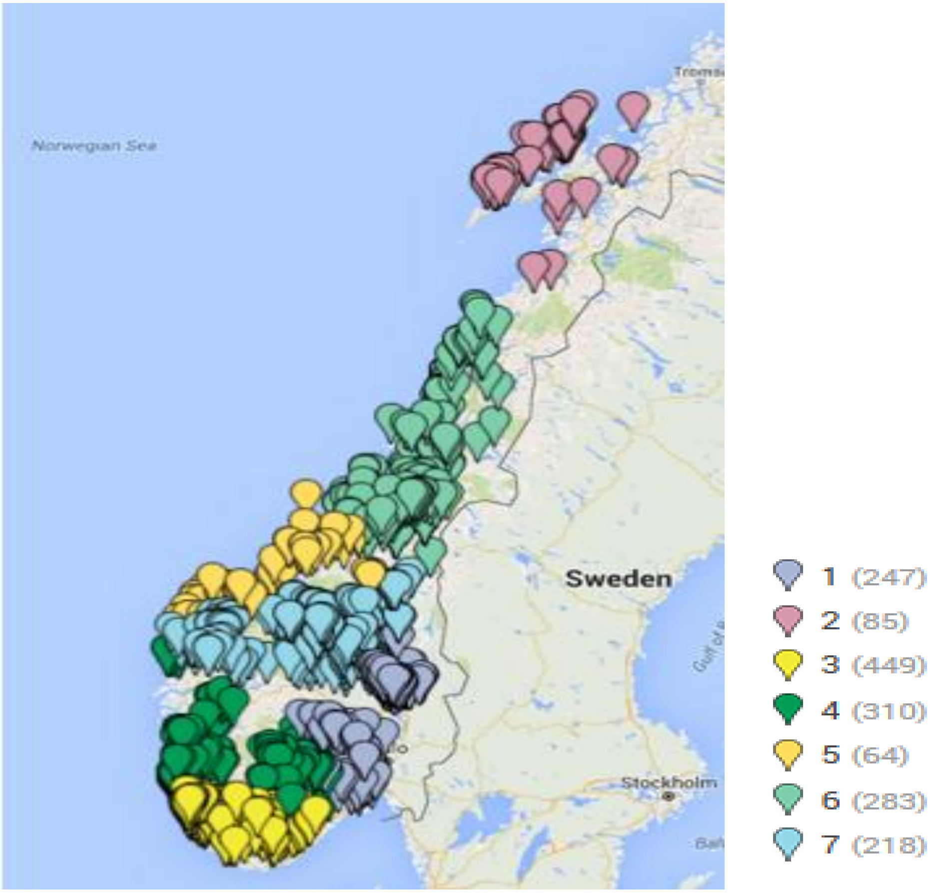


Figure 40. Distribution of the orders by location with the new collection point.

As it can be seen now, the distribution of the orders has changed in the central zone, where the new collection point receives the orders.

Again for this approach, the boundaries are well defined and there are no overlapping areas for each location since, as it was explained on the previous section, the influence of the weight in the trailers cost and thus in the total transport cost is significantly smaller due to the capacity of the trailers.

The study of the cost as it was done in previous sections is going to be carried out for the optimal solution.

Table 48. Results of the cost from the model with an additional collection point.

		Transport			
Location	**Set-up**	**Truck**	**Trailer**	**Total transport**	**TOTAL**
1	0	75289.47	0	75289.47	75289.47
2	0	52946.58	0	52946.58	52946.58
3	5000	72128.77	8968.32	81097.09	86097.09
4	5000	69507.28	4132.9	73640.18	78640.18
5	5000	19278.85	1454.85	20733.7	25733.7
6	5000	76596.7	8319.96	84916.66	89916.66
7	5000	66382.34	2388.15	68770.49	73770.49
Total	**25000**	**432129.99**	**25264.18**	**457394.17**	**482316.923**

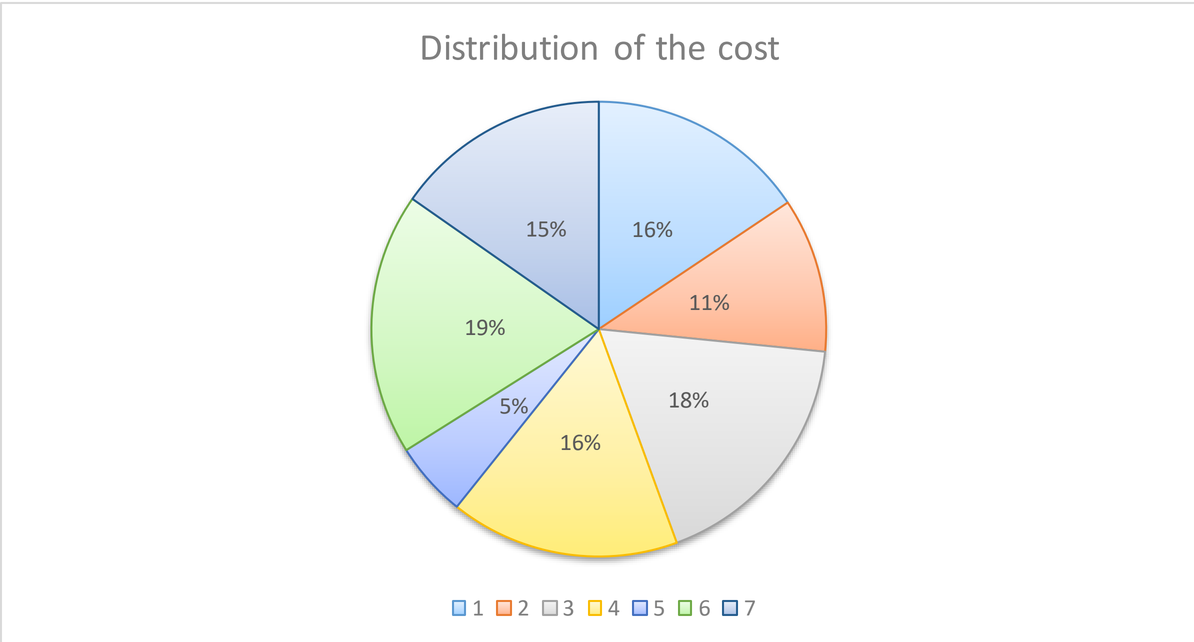


Figure 41. Distribution of the cost per location.

It is remarkable the significant cost of the new collection point 7, where it has a value of 15 %. Comparing to the results of the previous case where 6 locations for the order were available, it can be see how the factory 1 decreases from the value of 21% to 16%and also the collection point 5 reduces from 17% to 5%.

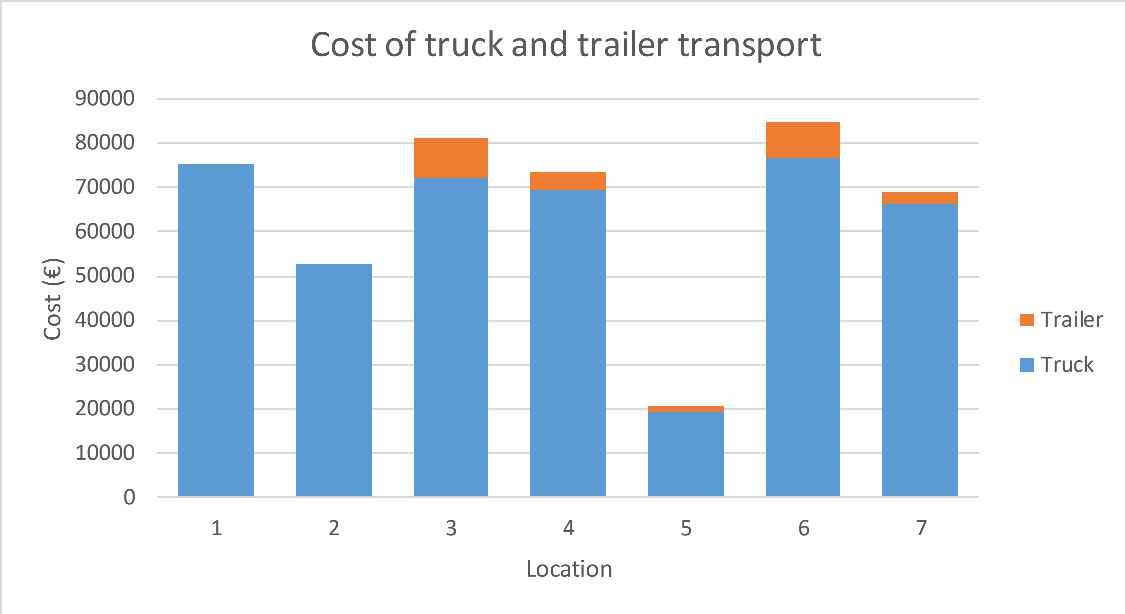


Figure 42. Truck and Trailer cost by location.

Regarding to the truck and trailer cost, in this case an overall reduction is achieved of the total cost, and thus, reduction on both. The biggest reduction is achieved on collection point 5, where it is diminished in 50 000€. Also, the reduction in factory 1 is remarkable, with a value of 30 000€.

Table 49. Disaggregated truck and trailer cost by location.

	Truck			Trailer		
Location	**Load**	**Distance**	**Total**	**Load**	**Distance**	**Total**
1	15123.1	60166.4	75289.5	0	0	0
2	5204.29	47742.3	52946.6	0	0	0
3	27490.9	44637.8	72128.7	1980.16	6988.16	8968.32
4	18980.4	50526.9	69507.3	1056.76	3076.14	4132.9
5	3918.53	15360.3	19278.8	425.218	1029.63	1454.848
6	17327.2	59269.5	76596.7	2097.16	6222.8	8319.96
7	13347.5	53034.9	66382.4	1085.69	1302.46	2388.15
Total	101391.92	330738.1	432130.0	6644.988	18619.19	25264.178

Table50. Disaggregated impact of the load and distance in the total transport cost by percentage.

	Truck			Trailer		
Location	**Load**	**Distance**	**Total**	**Load**	**Distance**	**Total**
1	3.31%	13.15%	**16.46%**			
2	1.14%	10.44%	**11.58%**			
3	6.01%	9.76%	**15.77%**	0.43%	1.53%	**1.96%**
4	4.15%	11.05%	**15.20%**	0.23%	0.67%	**0.90%**
5	0.86%	3.36%	**4.21%**	0.09%	0.23%	**0.32%**
6	3.79%	12.96%	**16.75%**	0.46%	1.36%	**1.82%**
7	2.92%	11.60%	**14.51%**	0.24%	0.28%	**0.52%**
TOTAL	22.17%	72.31%	**94.48%**	1.45%	4.07%	**5.52%**

Related to the impact of the transport cost in terms of percentages, it can be seen the influence of adding the new collection point. While the total impact on the transport cost for the truck and trailer remains similar in a value of 94 % and 5 % respectively, now the impact per location varies, specially, as it was said before, in factory 1.

The distribution of the orders, kilometres and weight also changes. The new distribution is represented below:

Table51. Distribution of orders, kilometres and weight by location.

		Nº Kilometers			Weigth(kg)		
Location	Nº of Orders	Truck	Trailer	Total	Truck	Trailer	Total
1	247	31701.57		31701.57	68750		68750
2	85	25155.32		25155.32	14300		14300
3	449	23519.6	260297.67	283817.27	78700	78700	157400
4	310	26622.54	148236.41	174858.95	42000	42000	84000
5	64	8093.33	25457.14	33550.47	16900	16900	33800
6	283	31228.97	137943.87	169172.84	83350	83350	166700
7	218	27943.97	42961.02	70904.99	43150	43150	86300

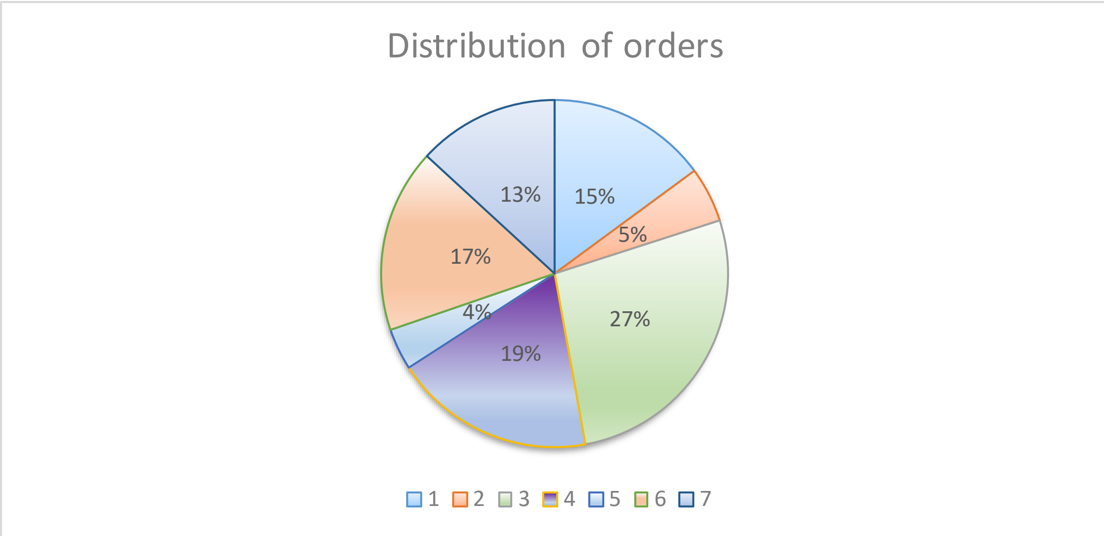


Figure 43 . Distribution of orders by location in percentage.

The distribution of the orders changes as it can be seen in comparison to the previous model. There is a huge reduction on the orders for locations 1 and 5 that will be taken by the new collection point.

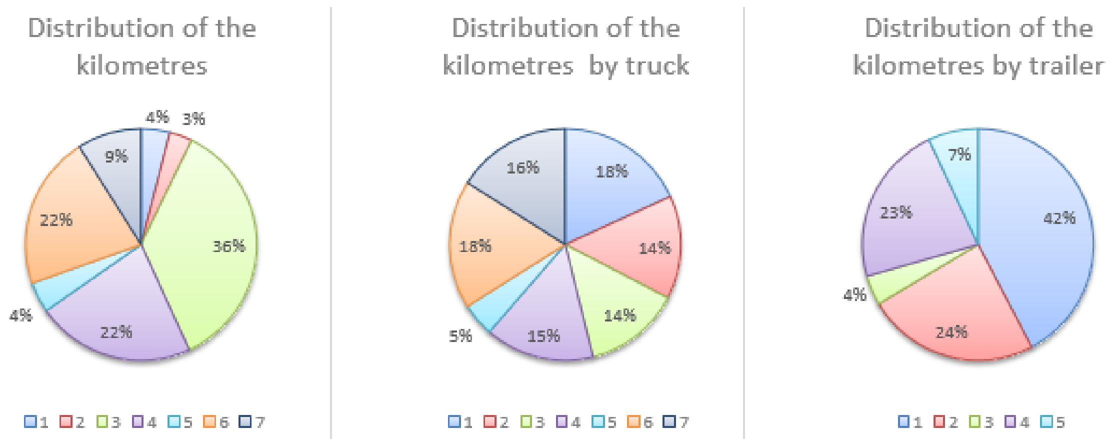


Figure 44. Distribution of kilometres in total, by truck and trailer for each location.

The distribution of the kilometres also varies in similar proportions to the orders variation in terms of truck. In terms of trailer, a big reduction is made in collection point 5 and the impact of the new collection point is remarkable.

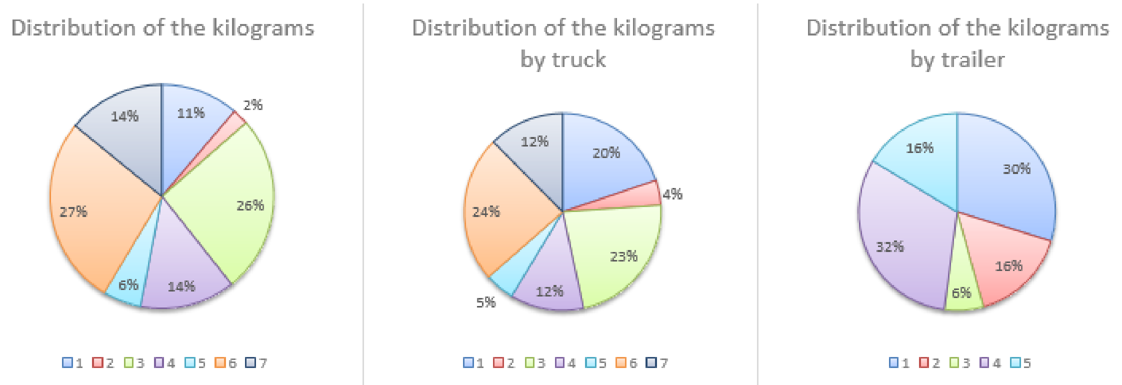


Figure 45. Distribution of kilograms in total, by truck and trailer for each location.

Now, as it can be observed from the images above, the reduction of the kilograms by collection point 5 is assumed by the appearance of the new collection point. The distribution of the cost per order when adding a new collection point and its comparison with the scenario with the 6 possible locations was made, and the results are shown in the table below:

Table 52. Cost per order distribution by location and variation.

	FTL	
Location	Cost per order	Difference (%)
1	304.815668	-5.3716%
2	622.9009412	0.0000%
3	191.7529844	0.0000%
4	253.678	-7.1771%
5	402.0890625	-11.0544%
6	317.7267138	-0.1676%
7	338.3967431	
TOTAL	291.2541806	-4.9841%

As it can be observed, an average reduction of almost 5 % of cost per order was achieved, with a maximum of an 11 % per order when it comes to collection point 5. In addition, it can be observed how a reduction on the cost per order was obtained in each location except for the locations 2 and 3, since the distribution of the optimal orders on those locations is not affected by the addition of a new collection point.

Regarding to the number of trailers, the difference between the previous models can be seen in the following table:

Table 53. Number of trailers.

	Number of trailers	
Collection point	FTL	Difference
3	7	0
4	4	0
5	2	-2
6	7	3
7	4	4

4.3.2. Not FTL approach

For the case where the model has not a FTL approach, the same procedure for the new location of the collection point is going to be made but only using the centre of gravity method since it led to the best results in the previous approach.

It can be seen in the table below the different locations for the new collection point attending to the different criteria (number of orders, total weight, number of kilometres and total cost by each location).It is important to remark that the weight and the kilometres taken into account were those made by the truck and the trailer since now the kilometres made by the trailer has a strong impact on the total cost.

Table 54. Location of new collection point by different factors

Location	X	Y	Orders	Weight	Kilometres	Cost
1	60.8323	11.09972	439	140800	84580.44	187403.87
2	69.24081	19.23436	95	19550	31729.91	66036.76
3	58.63039	5.599	413	66500	259015.55	168187.34
4	59.53082	5.84245	321	39200	180589.11	125692.38
5	62.98124	8.65731	144	23100	82928.26	87184.92
6	63.81768	11.00581	244	58000	143630	141541.44
		X	61.1399839	61.3788473	60.9197627	61.6457322
		Y	8.94923008	9.73225031	8.11929942	9.45677965

4.3.2.1. Results of model with new collection point using average

For a first approach, the average of all the possible locations was selected. This mean that it is located in (61.27108153, 9.064389866). It can be seen how the new possible locations are quite similar to those of the FTL approach but with the exception of the one using kilometres as factor.

Table 55 .Cost with a new collection point using average as factor for gravity centre method.

Cost	Set-up	Truck	Trailer	Total transport	TOTAL
TOTAL(€)	25000	478295.097	255740.403	734035.5	759035.5
% Δ	25%	-5.528%	2.393%	-2.911%	-2.19%

The results for using the average factor achieves a reduction of the total cost of 2.19 %.

4.3.2.2. Results of model with new collection point using weight as factor

The new collection point is going to be located at the coordinates given by using the gravity centre method using the weight as factor, as it can be seen in table 54. The results of placing the collection point at that location (61.3788473, 9.73225031) are show in the table below.

Table 56. Cost with a new collection point using weight as factor for gravity centre method.

Cost	Set-up	Truck	Trailer	Total transport	TOTAL
TOTAL(€)	25000	477052.805	257822.301	734875.106	759875.106
% Δ	25%	-5.774%	3.227%	-2.800%	-2.08%

The results using the weight as factor are worse of those obtained by using the average, despite the fact that achieves a bigger reduction on the truck cost, the trailer cost are much higher, so it terms in to a more expensive model.

4.3.2.3. Results of model with new collection point using cost as factor

Now, the cost as factor is going to be used in the gravity centre method. The location thus is going to be (61.64573222, 9.456779653), as it can be seen in the table 54.

The results of the model are shown in the following table:

Table 57. Cost with a new collection point using cost as factor for gravity centre method.

Cost	Set-up	Truck	Trailer	Total transport	TOTAL
TOTAL(€)	25000	470481.882	259825.95	730307.832	755307.832
% Δ	25%	-7.072%	4.029%	-3.404%	-2.67%

As it can be observed, the results are better than by using the average method for the gravity centre. Even while the trailer cost are much higher that just using the average, the truck cost achieves a big reduction of 7 %, which leads to the biggest reduction of the total cost.

4.3.2.4. Results of model with new collection point using distance as factor

Now, the distance as factor is going to be used in the gravity centre method. The location thus is going to be (60.91976268, 8.119299421).

Table 58. Cost with a new collection point using distance as factor for gravity centre method.

Cost	Set-up	Truck	Trailer	Total transport	TOTAL
TOTAL(€)	25000	483469.728	253605.47	737075.198	762075.198
% Δ	25%	-4.506%	1.539%	-2.509%	-1.80%

The results for this case are the lowest of all the approaches, despite the fact that it achieves the best trailer results, the reduction on the truck cost is the lowest.

4.2.3.5. Results of model with new collection point using orders as factor

The same procedure as before is going to be used. The location of the new collection point attending to the data of table 54 based on the orders is (61.3788473, 8.949230079)

Table 59. Cost with a new collection point using orders as factor for gravity centre method.

Cost	Set-up	Truck	Trailer	Total transport	TOTAL
TOTAL(€)	25000	473810.258	257405.61	731215.868	756215.868
% Δ	25%	-6.414%	3.060%	-3.284%	-2.5554%

The results now are better than by using the average but worse than by using the cost as factor. It can be seen how the trailer cost are less than in the cost-factor approach, but the truck cost are higher , which leads to a bigger result in the total cost.

4.3.2.6.. Results of model with new collection point using average-pondered as factor

As it was seen, the best reduction was obtained by using cost as a factor. However, it is going to be analysed the possible use of factors for achieve better results in order to optimize the location of the new collection point.

By analysing the cost related to the use of each factor individually, it was observed that the use of cost as factor is the one which achieves more savings.

Despite the fact all the possible new locations are placed in similar points, the total cost is quite different in each location.

The results and criteria for pondering each factor is shown in table below:

Table 60. Calculated pondering factors for average.

Factor	Total Cost	% of Total	
Currently	776046.71		Pondered
Weight	759875.106	2.0838%	0.22869404
Cost	755307.832	2.6724%	0.29328308
Orders	756215.868	2.5554%	0.2804419
Km	762075.198	1.8003%	0.19758099

So the location of the new collection point using the pondered values is (61.29942644, 9.113179318). The results obtained are: shown below.

Table 61. Cost with a new collection point using average-pondered as factor for gravity centre method.

Cost	Set-up	Truck	Trailer	Total transport	TOTAL
TOTAL(€)	25000	477264.374	256285.577	733549.951	758549.951
% Δ	25%	-5.732%	2.612%	-2.976%	-2.255%

As it happened in the FTL approach, in this case no optimization was achieved by using factors. The best results were obtained by using the cost as a factor, so that location (61.64573222, 9.456779653) is going to be used for the optimal location of the new collection point since it gives the optimal results. It is remarkable to notice how this location is quite similar to the FTL approach.

As it was seeing in the FTL approach, the optimal number of collection points was seven, the study of open another additional collection point is not going to be made in this approach since it will lead to the same results of not opening a second additional collection point, especially in this approach were the reduction achieved is less than in the previous approach in terms of percentages.

4.3.2.7. Results of the model for the optimal solution

As it was seen in this section, the optimal solution comes when the additional collection point was opened at the location determined by the use of the cost as factor under the centre of gravity method. For this location, the results of this solution are going to be studied.

Figure 46. Location of the collection points and factories.

The location of the additional collection point is quite similar to the previous approach, so it is expect that the location is not feasible to carry on due to construction in not possible places.

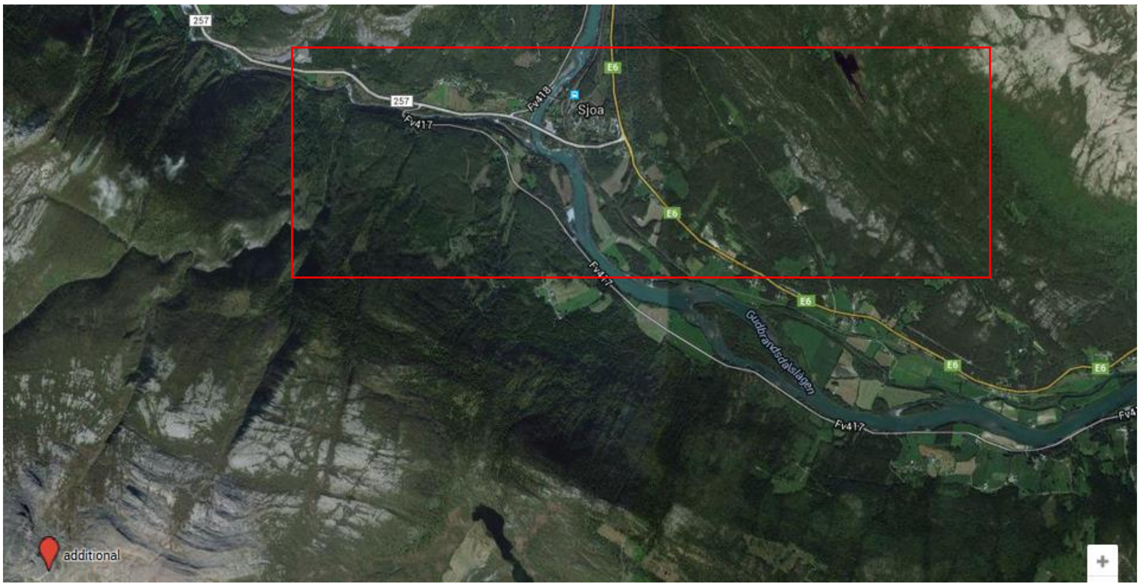


Figure 47. Possible location for the new collection point.

In this case, as it happened in the previous approach, the additional collection point was placed in a mountain, so it has to be more some kilometres. The red rectangle represent the possible construction zone for the collection point, where as it can be seen, there is a road near which is important for the transport consideration.

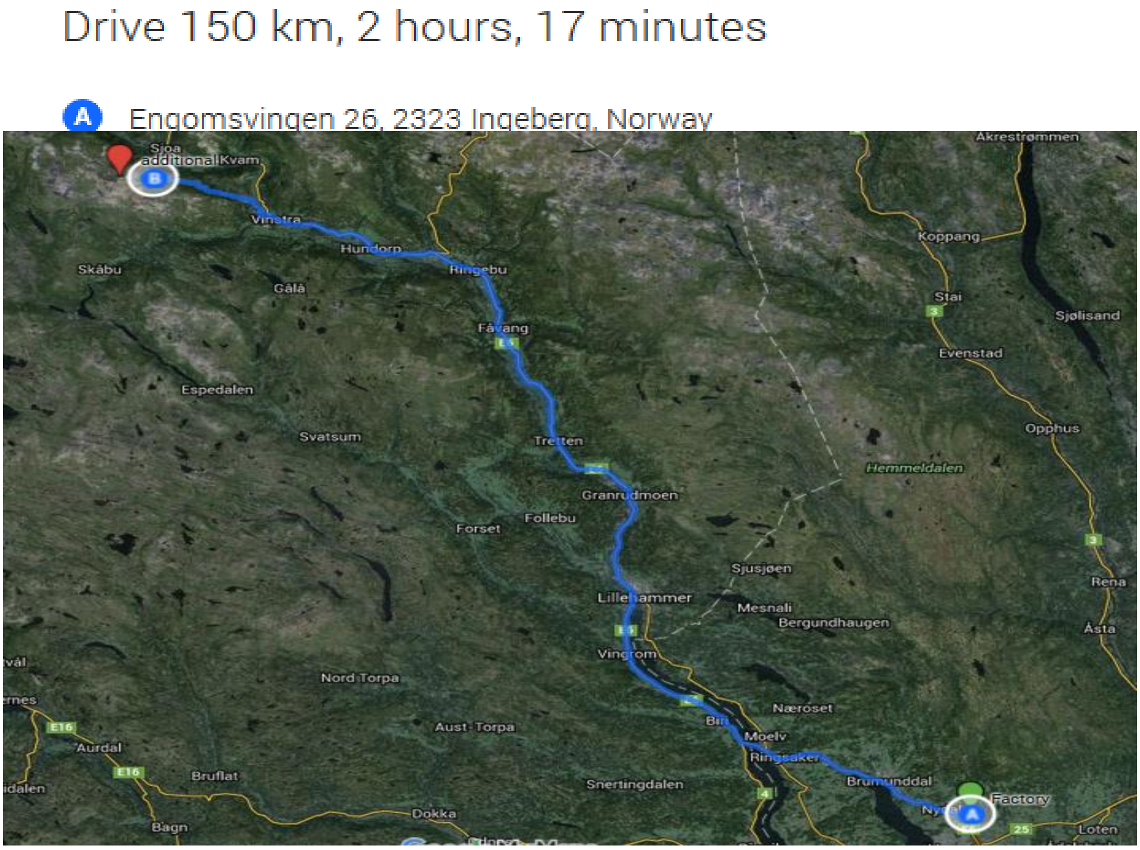


Figure 48. Distance to Factory 1 of the new collection point

As it can be seen, the new collection point would be allocated in a place near the road, and it will take 150 kilometres. This new location is quite similar to the obtained with the FTL case, with a driving time difference less than fifteen minutes.

The orders assigned to the optimal locations are represented in the image below.

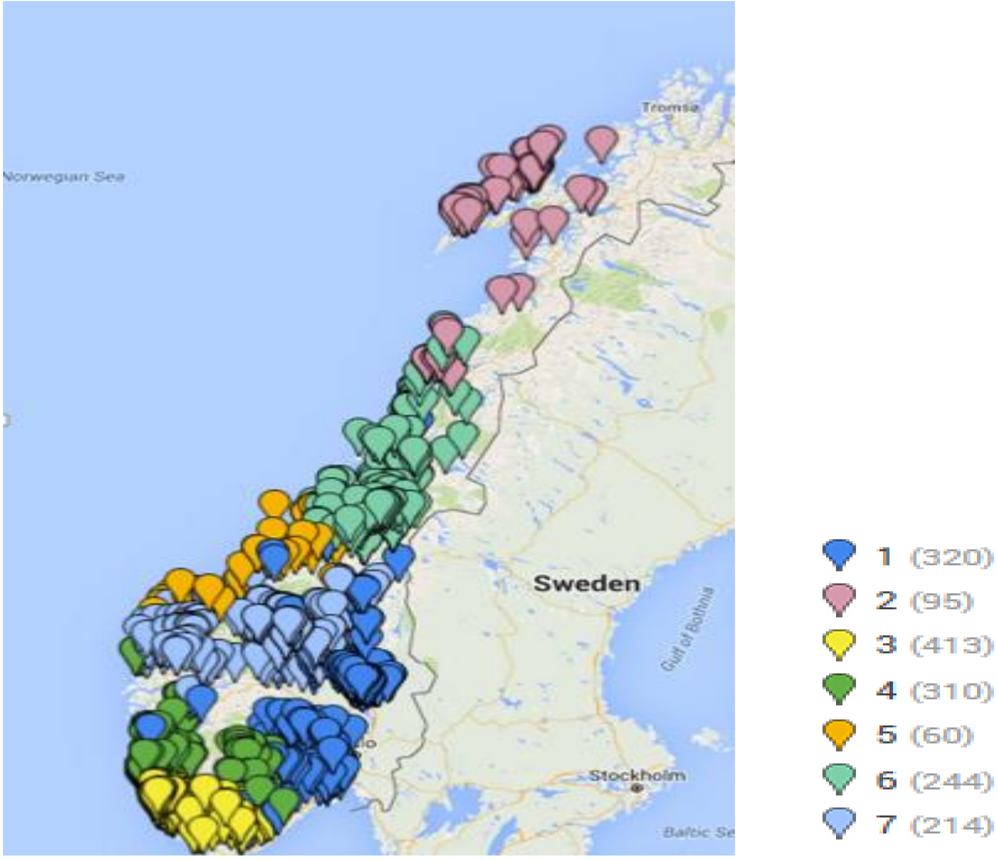


Figure 49. Distribution of the orders with the additional collection point.

As it happened in the scenario with the non-additional collection point, now the boundaries are again undefined and the existence of overlapping areas appear again. It can be notice how the additional collection point (number 7 in the picture above) has an important impact connected to the diminish on the impact of collection point number 5, which has the least amount of orders.

In this section, the study of the cost of adding a new collection point for the not FTL approach are going to be studied in comparison with the case of not additional collection points studied in previous chapters for the same approach of not FTL.

Table 62. Results of the cost from the model with an additional collection point.

		Transport			
Location	**Set-up**	**Truck**	**Trailer**	**Total transport**	**TOTAL**
1	0	128062.18	0	128062.18	128062.18
2	0	66036.76	0	66036.76	66036.76
3	5000	62462.96	100724.38	163187.34	168187.34
4	5000	64132.68	48733.22	112865.9	117865.9
5	5000	16650.71	16244.69	32895.4	37895.4
6	5000	61810.07	74731.37	136541.44	141541.44
7	5000	71326.53	19392.29	90718.82	95718.82
Total	**25000**	**470481.89**	**259825.95**	**730307.84**	**755307.84**

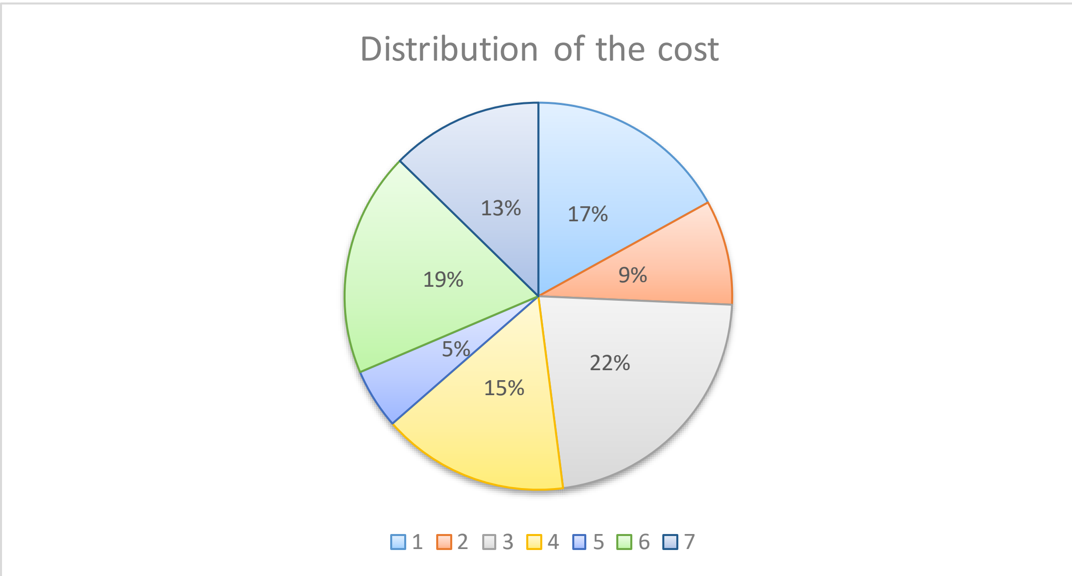


Figure 50. Distribution of the cost per location.

With the addition of the new collection point, it can be observed a reduction of the distribution of the cost in location 1 and 5 in favour of the new collection point, which has a total impact of 13%.

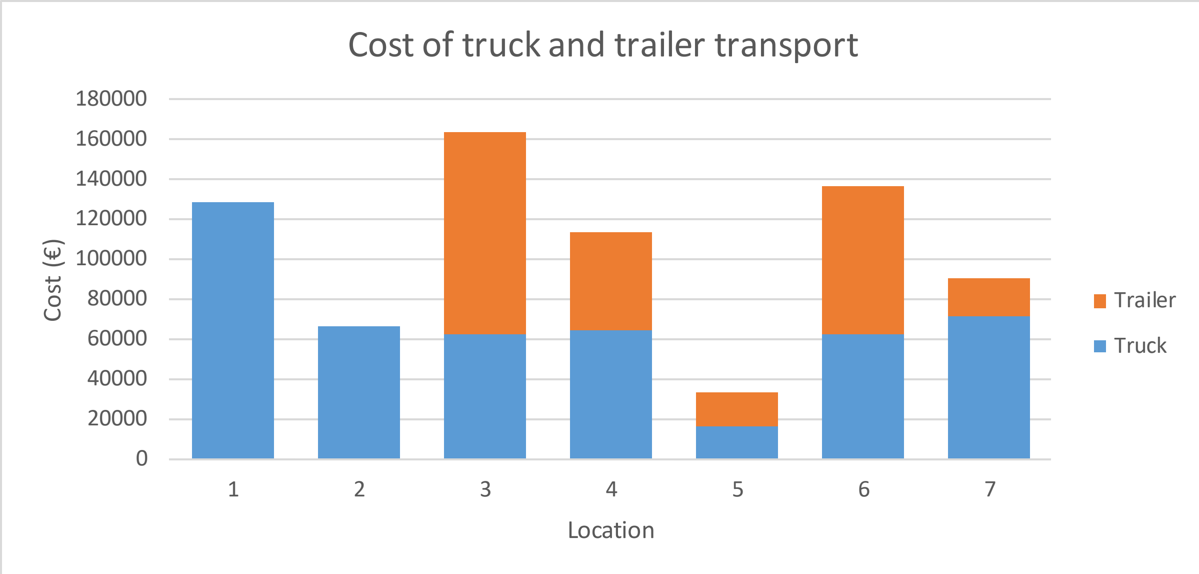


Figure 51. Truck and Trailer cost by location.

In comparison with the previous case of no additional collection points in the not FTL approach, it can be seen an overall reduction on the cost of truck and trailer. The biggest reduction is achieved in factory 1, with a value of almost 60 0000 € while in the collection point 5 the reduction goes around 50 000 €.

Table 63. Disaggregated truck and trailer cost.

	Truck			Trailer		
Location	**Load**	**Distance**	**Total**	**Load**	**Distance**	**Total**
1	19592.6	108470	128062.6	0	0	0
2	5816.56	60220.2	66036.8	0	0	0
3	25286.8	37176.2	62463.0	6246.57	94477.81	100724.38
4	18980.4	45152.3	64132.7	3616.43	45116.79	48733.22
5	3673.62	12977.1	16650.7	1427.79	14816.9	16244.69
6	14939.4	46870.7	61810.1	5448.13	69283.24	74731.37
7	13102.6	58224	71326.6	3334.63	16057.66	19392.29
Total	101391.98	369090.5	470482.5	20073.55	239752.4	259825.95

Table 64. Disaggregated impact of the load and distance cost on the total transport cost by location in terms of percentage

	Truck			Trailer		
Location	**Load**	**Distance**	**Total**	**Load**	**Distance**	**Total**
1	2.68%	14.85%	**17.54%**			
2	0.80%	8.25%	**9.04%**			
3	3.46%	5.09%	**8.55%**	0.86%	12.94%	**13.79%**
4	2.60%	6.18%	**8.78%**	0.50%	6.18%	**6.67%**
5	0.50%	1.78%	**2.28%**	0.20%	2.03%	**2.22%**
6	2.05%	6.42%	**8.46%**	0.75%	9.49%	**10.23%**
7	1.79%	7.97%	**9.77%**	0.46%	2.20%	**2.66%**
TOTAL	13.88%	50.54%	**64.42%**	2.75%	32.83%	**35.58%**

In terms of impact on the total transport cost by percentages, the values remain quite similar with the exception of a reduction in location 1 and 5, and the appearance of the impact of the new collection point, as it was previously described.

Table 65. Distribution of orders, kilometres and weight by location.

		Nº Kilometres			Weight(kg)		
Location	**Nº of Orders**	Truck	Trailer	Total	Truck	Trailer	Total
1	320	57152.4		57152.4	113900		113900
2	95	31729.91		31729.91	19550		19550
3	413	19588.08	239427.47	259015.55	66500	66500	133000
4	310	23790.67	148236.41	172027.08	38500	38500	77000
5	60	6837.6	23866.06	30703.66	15200	15200	30400
6	244	24696.07	118933.93	143630	58000	58000	116000
7	214	30678.09	39498.75	70176.84	35500	35500	71000

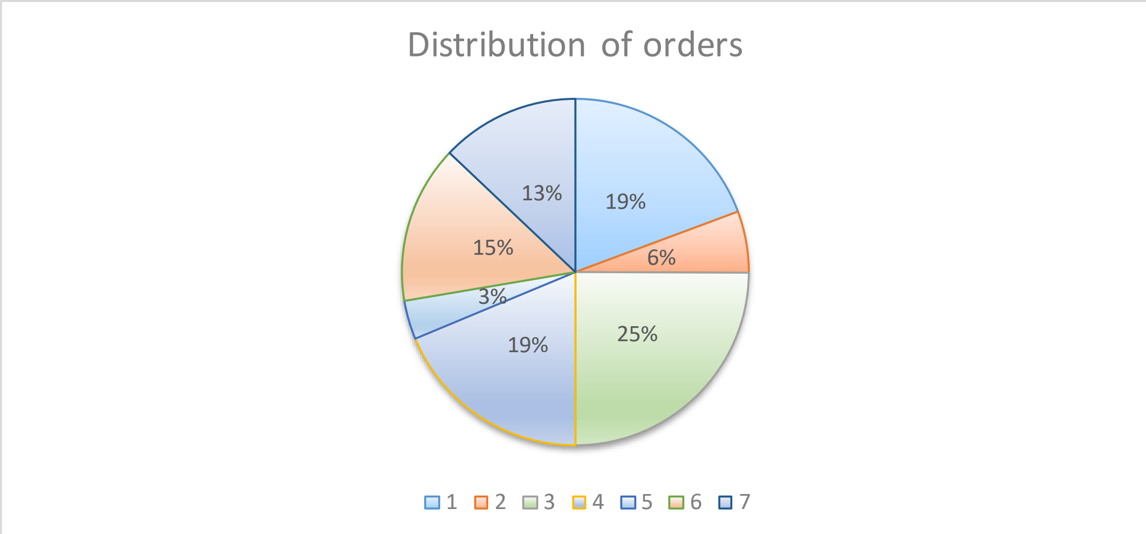


Figure 52. Distribution of orders by location in percentage.

The distribution of the orders has changed with a reduction of orders on factory 1 and collection point 5, and those orders were taken in majority by the new collection point.

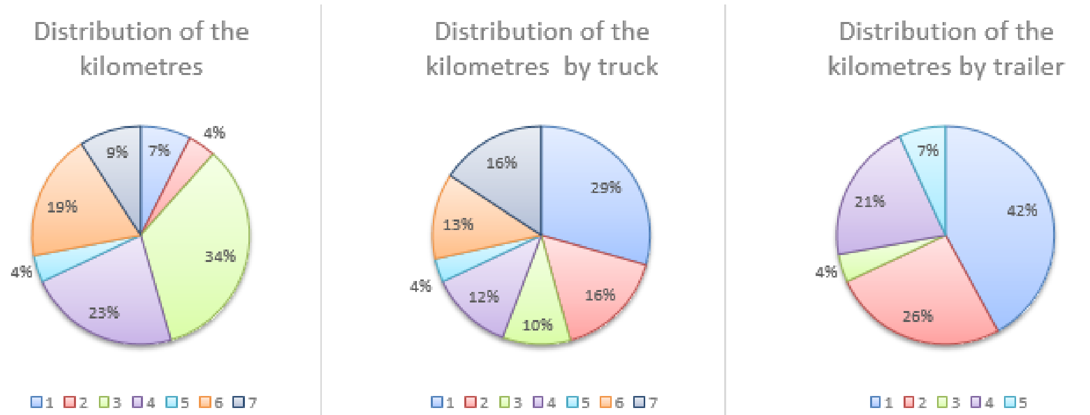


Figure 53. Distribution of kilometres, total, truck and trailer, by location in percentage.

The distribution of the kilometres follows the same structure in reduction than the previous one, with a reduction of the kilometres made by factory 1 and collection point 5 in favour of the new collection point.

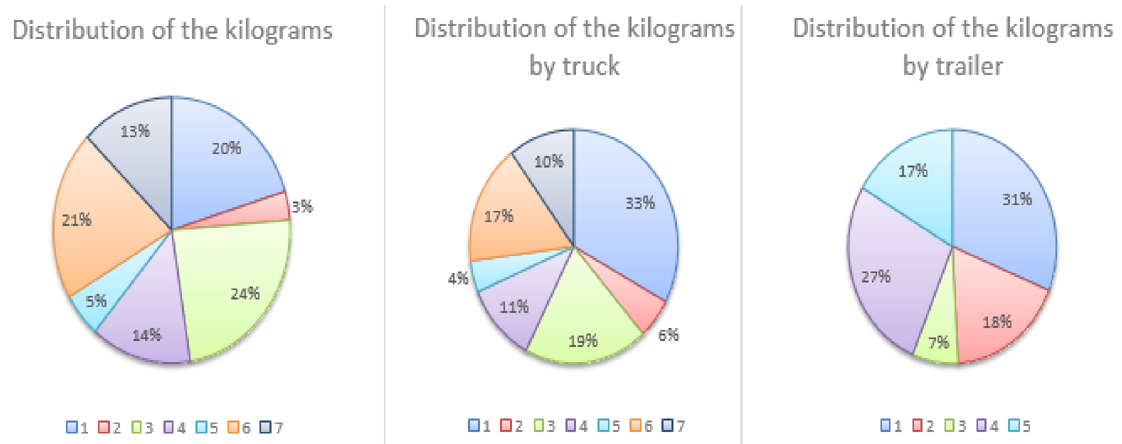


Figure 54. Distribution of kilograms, total, truck and trailer, by location in percentage.

For the distribution of the weight, it can be observed in comparison with previous results that the addition of a new collection point has the same effects than in the orders and kilometre scenario; a reduction from locations 1 and 5 and an important repercussion of the new added collection point.

The cost per order by adding an additional collection point and its difference in terms of percentage with the cost per order of the same approach without an additional collection point was made and the results can be seen in the table below, where as it can be observed, a reduction of an 2, 5 % in terms of average cost per order was achieved. It is remarkable to point out that while in the FTL approach there was no increase of the cost per order in any case, in this approach, the cost per order of collection point 5 suffers an increase of 4%, but still achieving an overall reduction of the total cost per order.

Table 66. Cost per order for not FTL approach with additional collection point.

	Not FTL	
Location	Cost per order	Difference (%)
1	400.1943125	-6.2531%
2	695.1237895	0.0000%
3	407.2332688	0.0000%
4	380.2125806	-2.8993%
5	631.59	4.3173%
6	580.0878689	0.0000%
7	447.2842056	
TOTAL	456.1037681	-2.6724%

Regarding to the number of trailers required in comparison with the previous scenario, the results can be seen in the table below, where as it can be seen, the results are quite different from the approach where no additional collection point was added.

Table 67. Number of trailers for the not FTL approach with additional collection point.

	Number of trailers	
Collection point	Not FTL	Difference
3	89	6
4	52	-1
5	21	-10
6	78	0
7	47	47

4.4. Fair distribution of the orders

In this section, the results for the described tool in the methods section are going to be shown. The approach followed in this case was the situation with the not-FTL, so that data were used. However, the procedure for the other approach would be the same but using other data, and would give the same results in terms of distributions of the new incoming orders.

For the calculation of the total kilometres, and thus, the total cost made by the transport company, they were calculated under the assumption that the transport company takes care of the full order, this means, first takes care of the truck cost of picking at the farm and carry it to the factories or the collection points and if it is necessary, the same transport company will take that order to the factories with the trailer.

The table below represents the currently cost spent in the diverse transports companies according to the assignments made by the model developed on the software.

Table 68. Total cost and total cost per order by truck and trailer for each transport company.

	Total Cost			Cost per order		
Transport Compa	Truck	Trailer	Total	Truck	Trailer	Total
Bakkevold	80807.39288	44891.35256	125698.7454	242.6648435	134.8088665	377.47371
Broderne Nervik	23285.06127	30521.30123	53806.3625	69.92510893	91.65555924	161.5806682
Edvardsen	54962.54398	10326.75176	65289.29574	165.0526846	31.01126655	196.0639512
LitraTransport	67265.29848	2084.022619	69349.3211	201.9978933	6.258326184	208.2562195
Surnadal	23879.35395	7175.97248	31055.32643	71.70977163	21.54946691	93.25923854
Tenden	64272.93873	6921.71027	71194.649	193.011828	20.78591673	213.7977448
Herredsvele	61840.70981	100342.9521	162183.662	185.7078373	301.3301866	487.0380239
Danielsen	13264.1165	2885.569781	16149.68628	39.83218169	8.665374716	48.49755641
Nervik	31693.02229	39214.9761	70907.99838	95.1742411	117.762691	212.9369321
Hellenstransport	85013.59099	5398.068704	90411.65969	255.296069	16.21041653	271.5064856

In addition, the difference by comparing a fixed cost per loading and taking an average 30% of the driving cost is going to be made. For doing this, the total kilometres and the total cost per kilometre per order for every transport company were calculated, and the cost of the load took an average value of 30 % of that cost.

The following table represents the difference on the cost of the load ,by taking the approach of fixed load cost for the not FTL case, that was calculated on the methods section, with the approach of taking an average value of 30% of the distance cost.

Table 69. Difference in cost per load by taking the different approaches.

Transport Company	km made by truck	Fixed Load Cost	Load Cost 30% of driving cost	Difference (€)	Difference (%)
Bakkevold	31834.55497	61.227	54.43135305	-6.795646952	-11.0991%
Broderne Nervik	8946.035235	61.227	49.45246681	-11.77453319	-19.2309%
Edvardsen	26475.61251	61.227	195.7716818	134.5446818	219.7473%
LitraTransport	27280.08192	61.227	61.39312349	0.16612349	0.2713%
Surnadal	10678.62424	61.227	103.0523438	41.82534384	68.3119%
Tenden	30219.86813	61.227	152.2680205	91.04102053	148.6942%
Herredsvele	19582.81723	61.227	27.66716785	-33.55983215	-54.8121%
Danielsen	6117.807842	61.227	129.0109723	67.78397226	110.7093%
Nervik	12698.70609	61.227	58.30856682	-2.918433176	-4.7666%
Hellenstransport	39502.7994	61.227	137.1445664	75.91756644	123.9936%

The average load cost with the 30% approach, had a value of 96.85 €, and as it can be seen, it varies in an interval of [27-195] euros, which is not a correct approach since a difference on the cost of loading of 170 € for doing the same work can lead to different results from the reality, so in terms of analysis of cost of the total logistic network, it was better to have a fixed value for the loading cost than a variable one which depends on the kilometres made.

Regarding to the distribution of the new incoming orders by the use of the developed tool explained in the methods section, the current situation of the different cost between the maximum cost and the transport company cost is represented in the next table.

Table 70. Currently total cost difference by each transport company.

Transport Company	Total Cost difference (%)
Bakkevold	-29.026%
Broderne Nervik	-201.421%
Edvardsen	-148.408%
LitraTransport	-133.865%
Surnadal	-422.241%
Tenden	-127.803%
Herredsvele	0.000%
Danielsen	-39.521%
Nervik	-128.724%
Hellenstransport	-79.384%
TOTAL	**-131.039%**

For minimizing that difference, several orders were created with the same coordinates in order to discover how many new orders the customer company would need to minimize the difference by setting them to a general value of less the 1% of difference.

In general, to minimize the total cost , it was repeated several times an average order with a Latitude of 61 and a Longitude of 8.45, and a weight of 200 kilograms, which are the average values for the latitude, longitude and weight obtained from the data of the orders.

To achieve a value of 0.145% of the average difference between the costs of the transport companies, the required distribution of the orders is represented:

As it can be observed by looking at the results, more than 1000 new orders were required in order to establish a minimum difference between the transport companies. This is because, the current distribution had differences with the value of 400% between the companies, so there were several differences in terms of cost for the transport companies, but, after the minimum difference was achieved, those differences would not be repeated anymore, so it will not cause problem among the different transport companies because of the unequal distribution of the orders, which resulted, as it was seen, in unbalanced salary among them.

Table 71. Total cost difference achieved.

Transport Company	Total Cost
Bakkevold	-0.274%
Broderne Nervik	-0.162%
Edvardsen	-0.053%
LitraTransport	-0.137%
Surnadal	0.000%
Tenden	-0.093%
Herredsvele	-0.138%
Danielsen	-0.104%
Nervik	-0.194%
Hellenstransport	-0.289%
TOTAL	**-0.145%**

Table 72. Distribution of the orders required for minimizing the difference.

Transport Company	Currently number of orders	Number of orders to <1 % of Total Cost
Bakkevold	333	391
Broderne Nervik	103	245
Edvardsen	77	205
LitraTransport	253	377
Surnadal	59	227
Tenden	113	234
Herredsvele	403	419
Danielsen	27	212
Nervik	124	246
Hellenstransport	164	263
TOTAL	1656	2819

4.5. Sensitivity analysis

In this section, a sensitivity analysis is going to be carry out in order to identify the possible factors that could have more influence the results and thus could be identified as risks. The detection of the possible risks in the logistic networks is an important approach that should be taken into consideration, not only to identify the risk but also to try to find solutions that could act as risks mitigation in case the risk represents a strong influence in the overall performance of the logistic network.

4.5.1. Variation on fuel cost

As it was described previously, the price of fuel fluctuates widely along the year and this can alter the cost of the logistic networks since transportation cost are the main cost which depends on the fuel cost.

For this reason, a sensitivity analysis of the impact of the variation of the fuel cost in the total cost of this model was carried out.

With a variation of fuel cost within a range of [-75%, 150%], the values of the cost per kilometre, both in the truck and in the trailer are expected to change. It is important to remark that, as it was explained in the cost per load, in the methods section, since the cost per load was assumed with no fuel consumption, the price of the load is not going to change.

Table 73. Variation of cost of kilometre of truck with fuel cost variation.

Variation on fuel cost	Cost per km
25%	2.01553828
50%	2.13316645
75%	2.25079462
100%	2.36842279
125%	2.48605096
150%	2.60367913
-25%	1.78028194
-50%	1.66265377
-75%	1.5450256

Table 74. Variation of cost of kilometre of trailer with fuel variation.

Variation	Cost per km
25%	1.98045467
50%	2.12279769
75%	2.26514071
100%	2.40748373
125%	2.54982675
150%	2.69216977
-25%	1.69576863
-50%	1.55342561
-75%	1.41108259

The results of the sensitivity analysis, in the case of variation on fuel price and its impact on the total cost, for the two approaches in this problem, the FTL and the not FTL approach, are shown in the table below:

Table 75. Variation of total cost due to fuel cost variation.

	Not FTL		FTL	
Increase on fuel	Total Cost	Increase %	Total Cost	Increase %
25%	819134.543	5.552%	553839.807	9.106%
50%	862201.924	11.102%	555309.18	9.395%
75%	905267.796	16.651%	579153.705	14.093%
100%	948329.965	22.200%	602998.231	18.790%
125%	991385.746	27.748%	626842.757	23.487%
150%	1034441.31	33.296%	650687.283	28.185%
-25%	732979.838	-5.550%	483775.602	-4.697%
-50%	689890.358	-11.102%	459931.049	-9.394%
-75%	646793.069	-16.655%	436086.484	-14.091%

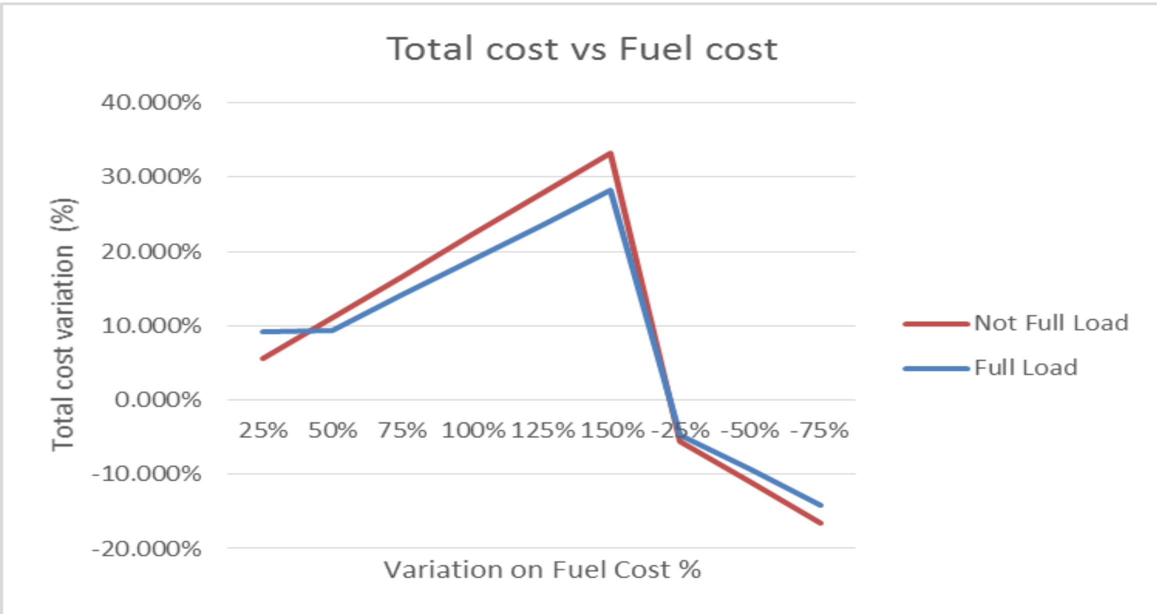


Figure 55. Variation of total cost by fuel variation.

As it can be seen, the variation on the total cost is less than the variation on the price of the fuel, and also, the impact on the FTL model is smaller than in the case of the not FTL, with the exception of an increase of a 25 % of the fuel cost, which in that case, the FTL approach seems more affected than the not FTL. An increase of a 150% on the fuel cost results in an increase of the total cost of 30 %., while a reduction of 75% achieves a reduction of 15 %. It is remarkable how, in the FTL approach, an increase of 50 % of the fuel cost has almost the same increase an increase of 25%, just 9 % increase of the total cost, but it is noticeable how the effect of increment the fuel cost on 25 % on both cases, led to significant differences between both approaches. It can also be observed the minor influence of the FTL approach when it comes to a reduction of the fuel cost, so the total cost does not decrease as much as the not FTL approach does, which means that it is more sensible to the variation of the fuel price.

The same analysis was conducted for the case were an additional collection point was added, to see the influence of the variation in the fuel cost when the optimal number of collection points is settled.

Table 76. Variation of total cost due to fuel cost variation in case of adding additional collection point.

	Not FTL		FTL	
Increase on fuel	**Total Cost**	**Increase %**	**Total Cost**	**Increase %**
25%	796760.641	5.488%	525399.013	8.932%
50%	838193.343	10.974%	526837.848	9.231%
75%	879622.423	16.459%	548808.085	13.786%
100%	921047.612	21.943%	570778.322	18.341%
125%	962465.701	27.427%	592748.559	22.896%
150%	1003883.57	32.911%	614718.797	27.451%
-25%	713876.517	-5.485%	460927.137	-4.435%
-50%	672426.668	-10.973%	438956.872	-8.990%
-75%	630967.275	-16.462%	416986.595	-13.545%

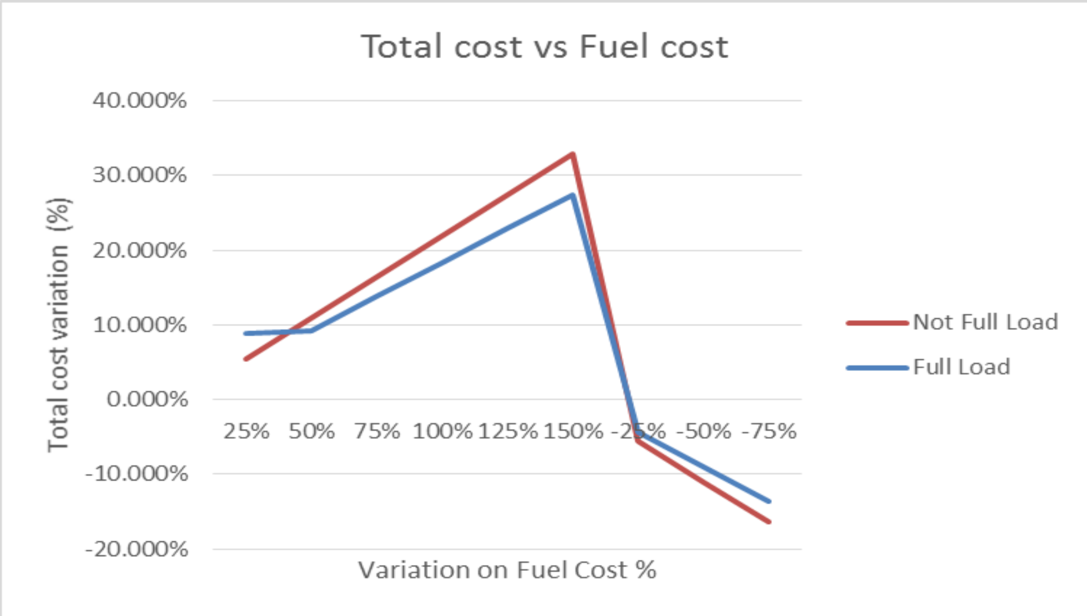


Figure 56. Variation of total cost in case of fuel variation in additional collection point.

It can be observed, by comparing this results to the previous ones, that the effect of a variation of the fuel price on the total logistics cost when an additional collection point is established, results into a less impact on the total cost than in the case with no additional collection point for both approaches. The same pattern repeats than in the previous case, but now, the values of the total cost are less compared to the values of the previous one when the same variation of the fuel cost occurs.

This means that, in case a reduction in the risks associated with the variation of the fuel price is needed to be take into account, because some logistic networks are more sensible than others to the changes, it should be considered to open the additional collection point, since it would work as a risks mitigation and it will reduce the impact the fuel variation produces in the total cost, and this will be especially useful in times where the fuel cost fluctuates widely or if the logistic networks has a strong dependence of the fuel cost, up to the point that it could stop being profitable if the fuel cost achieves certain value, so this scenarios should be contemplated also when taking the decision of opening an additional collection point, not only the potential savings.

4.5.2.. Utilization rate

As it was seen before, the utilization rate, related to the capacity used by the trailer, is critical in this model since it influences critically the behaviour of the model and thus the results obtained.

In this section, it was analysed the impact that the variation of the utilization rate has on the total cost of the model.

The table below expresses the variation on the total cost of the model in case the same value of the cost per load and cost per km is maintained, but the capacity used by the trailer and thus the utilization rate increases.

Table 77. Variation of total cost with the variation of the utilization rate.

Capacity	Utilization rate	Cost	Cost variation %
750	6%	776046.7	0.0%
1200	10%	675434	-13.0%
1650	14%	626125	-19.3%
2100	18%	596859	-23.1%
2550	21%	577314	-25.6%
3000	25%	563452	-27.4%
3450	29%	553038	-28.7%
3900	33%	544988	-29.8%
4350	36%	538581	-30.6%
4800	40%	533368	-31.3%
5250	44%	529032	-31.8%
5700	48%	525366	-32.3%
6150	51%	522234	-32.7%
6600	55%	519527	-33.1%
7050	59%	517162	-33.4%
7500	63%	515081	-33.6%
7950	66%	513235	-33.9%
8400	70%	511586	-34.1%
8850	74%	510103	-34.3%
9300	78%	508764	-34.4%
9750	81%	507549	-34.6%
10200	85%	506440	-34.7%
10650	89%	505425	-34.9%
11100	93%	504492	-35.0%
11550	96%	503631	-35.1%
12000	100%	502834	-35.2%
13000	108%	497717	-35.9%
16000	133%	497717	-35.9%
18000	150%	496011	-36.1%
20000	167%	494646	-36.3%
22000	183%	493530	-36.4%
24000	200%	492599	-36.5%

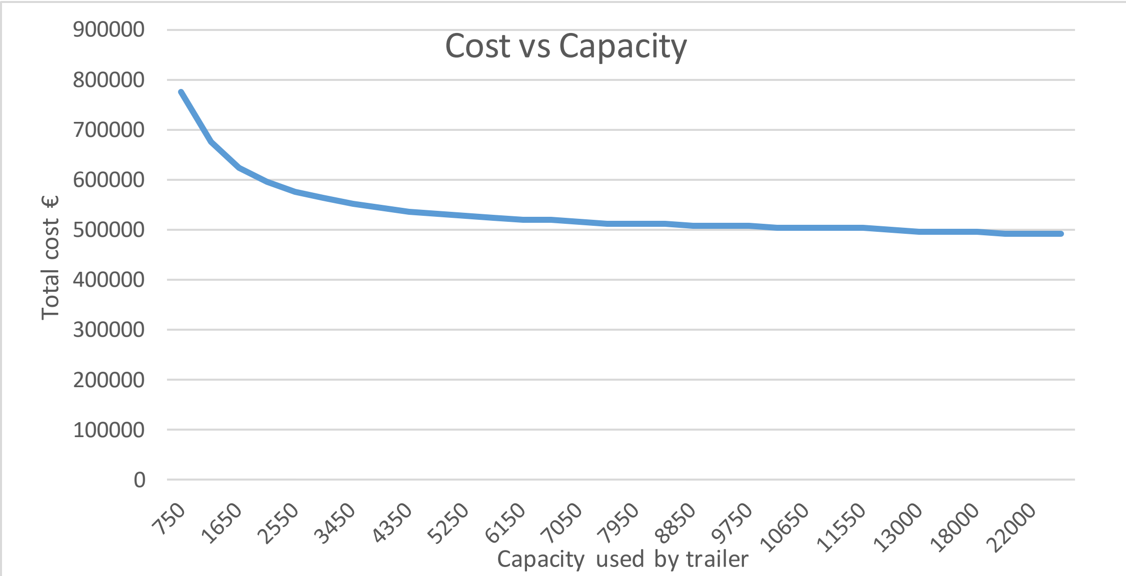


Figure 57. Variation of cost with capacity.

By analysing the results, it could be observed how the increase on the utilization rate achieves an overall reduction of the total cost. It is remarkable the strong reduction it is achieved at low utilization rates, where the slope has bigger values achieving strong reductions and after it stablishes around a 30% of the total cost reduction, regardless the capacity used. Even when the capacity is doubled, the variation in the total cost remains in the 30%, so it can be concluded that it may not be worth it to make an effort to use a utilization of the trailers to bigger values than a 30% since the impact on the total cost would not be appreciated.

Since it could be unrealistic that the utilization factor improves while the cost per load still the same, (as it was explained in the methods sections, the cost per load depends on the capacity), it was estimated a new cost per load based on the total cost variation. The results are expressed in the following table, where the cost variation can be seen.

Table 78. Variation of total cost with the variation of the utilization rate in case cost per load increases.

Capacity	Cost per load	Total Cost	Cost variation %
750	70.45	776046.7	0.0%
1200	79.58367983	677048	-12.76%
1650	84.0599855	627949	-19.08%
2100	86.71677107	598650.5	-22.86%
2550	88.49107825	578974.8	-25.39%
3000	89.74947918	564996	-27.20%
3450	90.69486853	554458.9	-28.55%

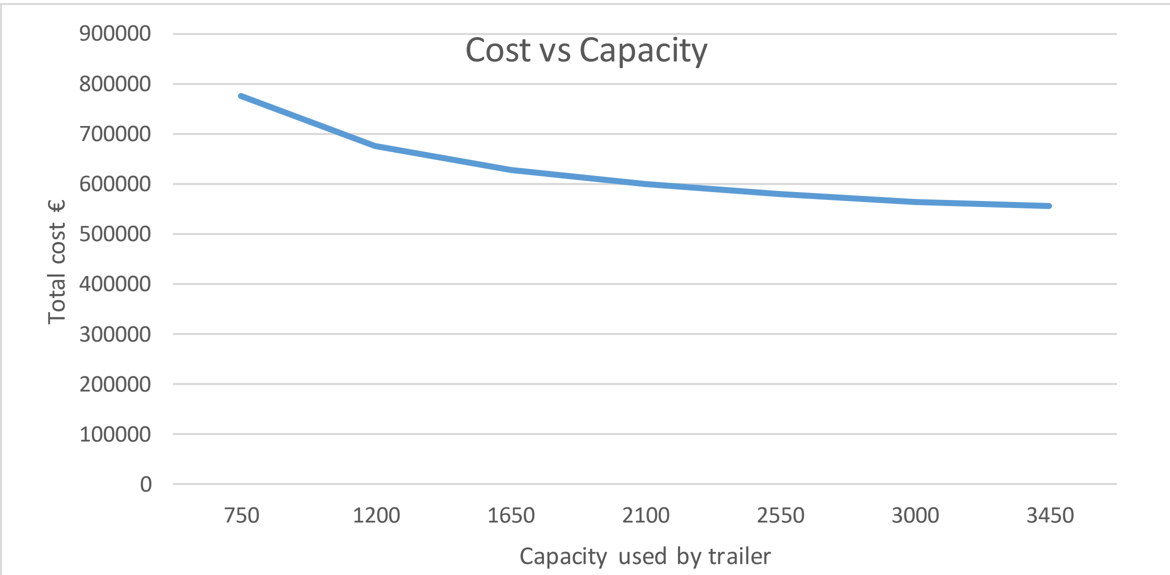


Figure 58. Variation of total cost vs capacity with load cost variable.

By representing the total cost when the load cost changes, it can be observed more clearly the impact of the utilization rate on the total costs, and how the slope goes progressively diminishing, so, depending on how the cost per load increases with the increase of the utilization rate, it will be better to set up the utilization rate to certain values. In this case, those values are around 25-30 % of the utilization rate.

The same analysis was done for the model with the additional collection point. The results are represented in the following table:

Table 79 . Variation of total cost with the variation of the utilization rate in case of additional collection point.

Capacity	Utilization factor	Cost	Cost variation %
750	6%	755307.8	0.0%
1200	10%	651390.9	-13.8%
1650	14%	600825.8	-20.5%
2100	18%	571228.3	-24.4%
2550	21%	551670	-27.0%
3000	25%	537811.7	-28.8%
3450	29%	527425.8	-30.2%
3900	33%	519420.4	-31.2%
4350	36%	513055.3	-32.1%
4800	40%	507882.2	-32.8%
5250	44%	503596	-33.3%
5700	48%	499981.6	-33.8%
6150	51%	496894.7	-34.2%
6600	55%	494228.6	-34.6%
7050	59%	491901.9	-34.9%
7500	63%	489852.8	-35.1%
7950	66%	488035.7	-35.4%
8400	70%	486412.1	-35.6%
8850	74%	484951.8	-35.8%
9300	78%	483632.8	-36.0%
9750	81%	482435.5	-36.1%
10200	85%	481343.4	-36.3%
10650	89%	480342.9	-36.4%
11100	93%	479423.3	-36.5%
11550	96%	478574.8	-36.6%
12000	100%	477789.7	-36.7%
13000	108%	476238.6	-36.9%
16000	133%	472747.3	-37.4%
18000	150%	471066.4	-37.6%
20000	167%	469721.6	-37.8%
22000	183%	468621.1	-38.0%
24000	200%	467703.1	-38.1%

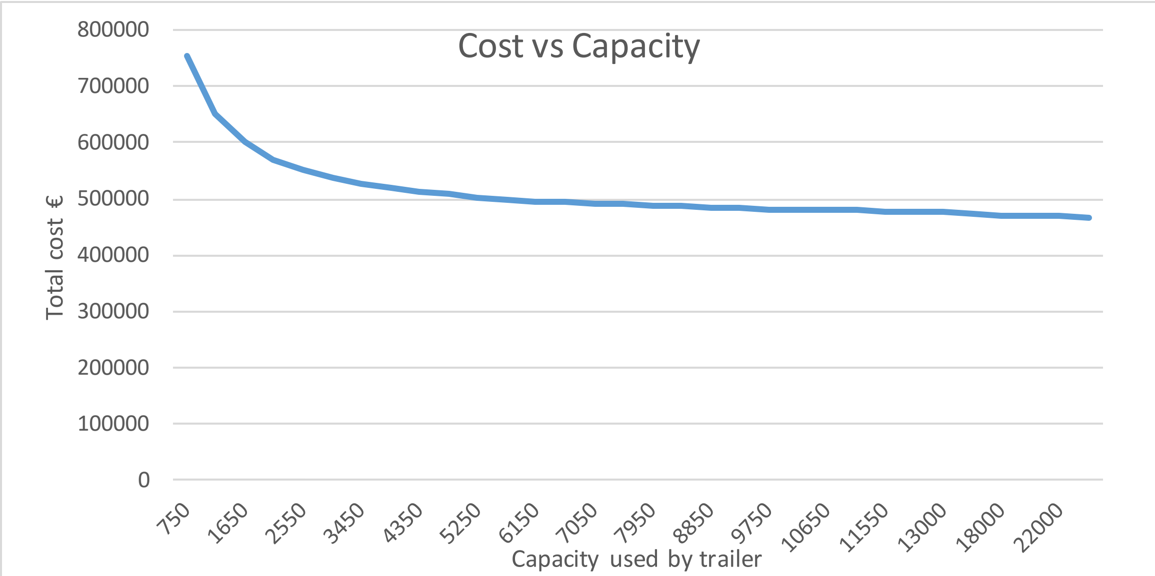


Figure 59. Variation of cost with capacity additional model.

As it can be observed, by adding a new collection point, the cost variation due to an increase of the utilization factor is bigger than in the case with no additional one, so the additional collection centre enhances its influence but again, the maximum achieve even when the capacity is double, which means than the utilization factor is 200%, but in terms of the strong reduction, it can be concluded that it is interesting to increase the utilization factor to values of 30%.

The same study when the cost per load changes with the improvement of the utilization factor was done, and the results are presented below:

Table 80. Variation of total cost with the variation of the utilization rate in case cost per load increases.

Capacity	Cost per load	Total Cost	Cost Variation (%)
750	70.45	755307.833	0.0%
1200	79.58367983	653211.518	-13.5%
1650	84.0599855	602861.517	-20.2%
2100	86.71677107	573192.905	-24.1%
2550	88.49107825	553479.803	-26.7%
3000	89.74947918	539491.69	-28.6%
3450	90.69486853	528966.495	-30.0%

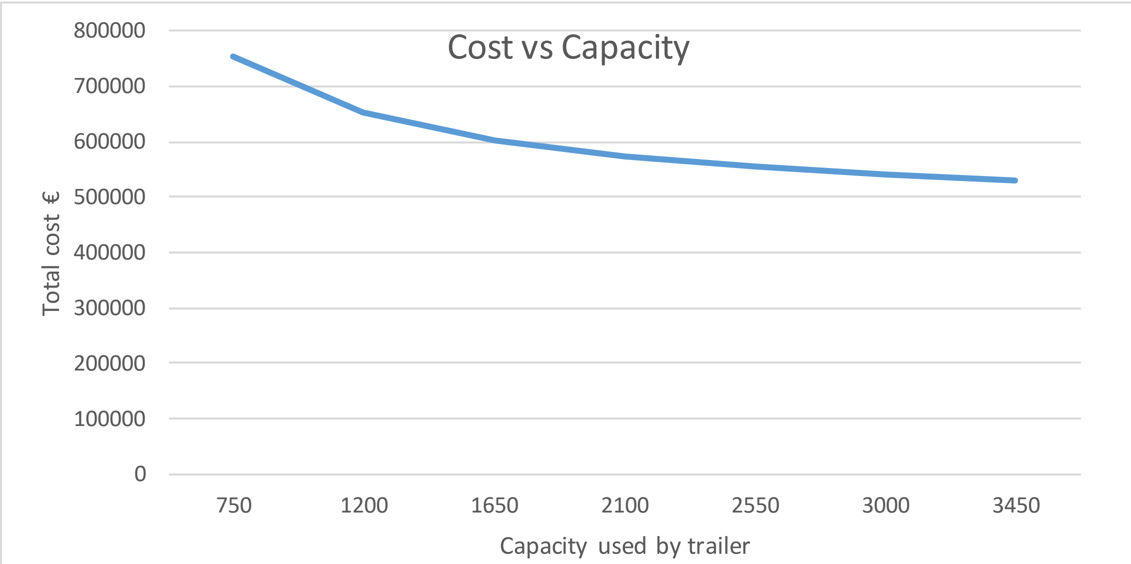


Figure 60. Variation of total cost vs capacity with load cost variable

By looking at the results when the price per load changes, it could be observed that the stronger influence happens again at around a value of 30% of the utilization rate, so it can be inferred that while the best solution in terms of performance will be to have the maximum capacity, the optimal solution if the price of enhance that capacity is taken into account, is going to be around that value. In addition, it can be observed how, by adding a new collection point, the results of increasing the capacity of the trailers, and thus the utilization rate, achieves a better performance, so the addition of a new collection point also works in terms of enhance the results of performance when the capacity varies.

4.6.3. Practical solution for improvement

By taking into account the different values and impacts that each factor made in the total cost at along this work, in this section, a practical solution based on the previous results is going to be approached.

First, it could be seen that the influence of opening a new collection point led to better results, so this approach is going to be taken.

Second, it was seen that the utilization factor achieves the greatest impact with values of 30%, so this value is going to be used. To this increase on the utilization factor, an increase of the cost per load is going to be also set. In addition it was observed that it performance better when the additional collection point is opened.

Also, the scenario with a decrease of 25 % of fuel cost is going to be used.

As a resume:

- Capacity 3450 kilograms, increase cost per load of trailers on 28.74%.
- Additional collection point added, required investment 5000€
- Fuel decrease 25%. Decreases cost of kilometre of truck on 6.20% and on trailer of 7.74%.

The combined results for this scenario turns into a total cost of 503459.701€, which represents a 33.34% of reduction on the total cost with the scenario of an additional collection point added but utilization factor of 6.25 % , and 35.13 % in comparison with the same approach but without the additional collection point.

Regarding to the difference with the approach of FTL, the difference with it is of bigger for the model with the additional collection point 4.38 %. This difference is quite small if the difference on the capacity used by the trailer (about 8000 kilograms) is taken into account, and it is related with the utilization rate performance, where, as it was seen, it achieves stronger reduction in terms of percentages in the zone of the low utilization rates. If the comparison is with the model without a collection point, the cost in this case is even lower, 0.57%, which is quite remarkable due to the difference in the capacity.

In the following table, the number of trailers required for each location and its difference between the practical case, the not FTL approach and the FTL one are shown.

Table 81. Number of trailers required for the different approaches

	Number of trailers		
Collection point	**Practical**	**Difference not FTL**	**Difference FTL**
3	23	-66	7
4	12	-40	4
5	5	-16	2
6	25	-53	7
7	13	-34	4

As it can be seen, by increasing the utilization rate to the values of the practical solution, an important reduction in the number of trailers required is achieved, and the difference with the FTL approach, where the utilization rate has a value of 100 %, which requires a huge investment to achieve, is not as higher as it is between the two approaches.

The results in the map for the practical solution are shown below:

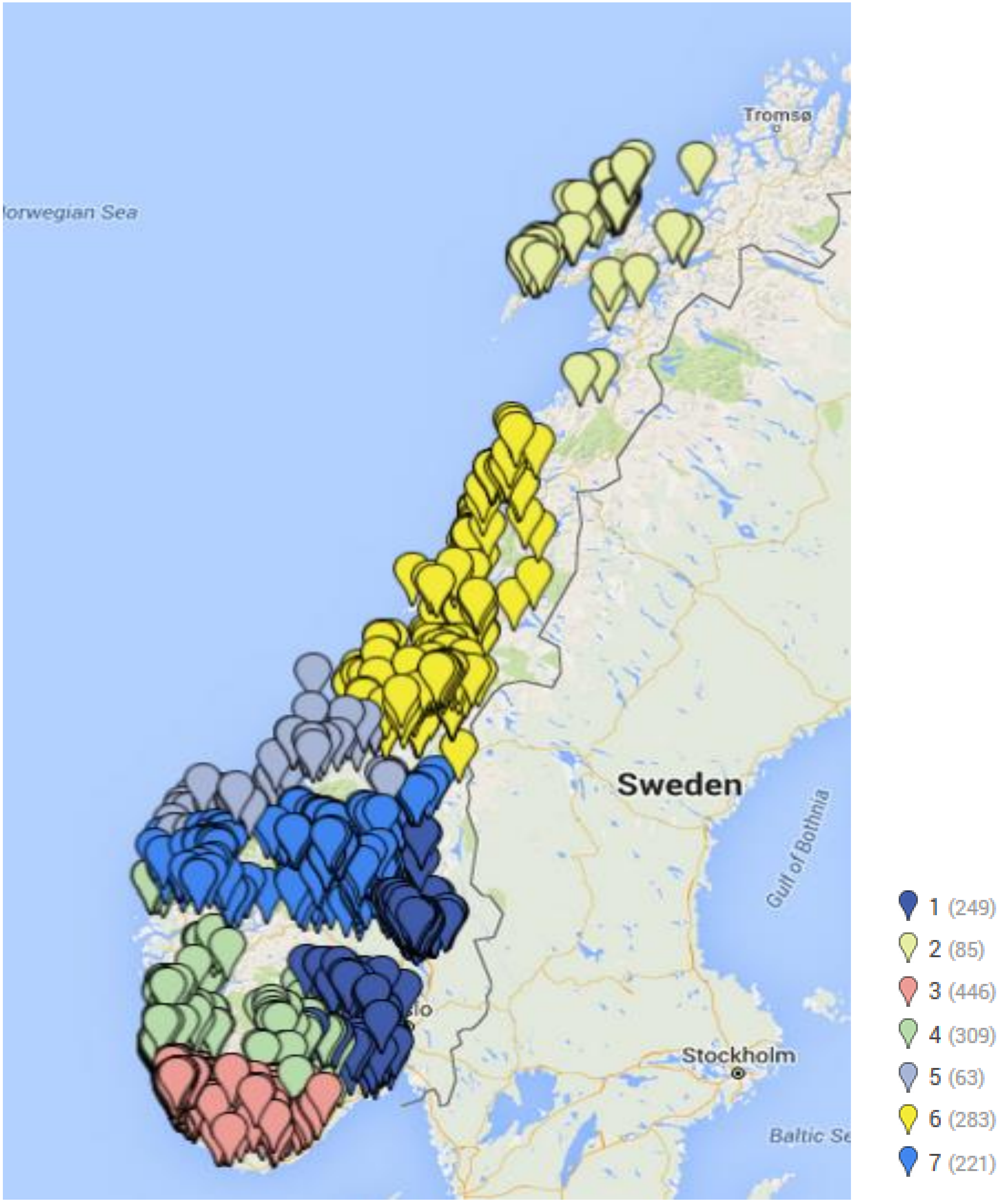


Figure 61. Results on the map for the practical solution.

As it can be observed, the overlapping areas in the practical solution still exist, but they are reduced up to the point to performance almost like the FTL approach. This means, that with the approach of 30 % of utilization rate, results almost close to the optimal ones are achieved but with a minor investment.

The distribution of the orders, represented in the following table, are quite similar to the optimal performance made by the FTL approach.

Table 82. Distribution of the orders for the practical case.

Location	Nº of Orders
1	249
2	85
3	446
4	309
5	63
6	283
7	221

5. CONCLUSIONS AND FUTURE WORK

In this work, different approaches were made for optimizing the logistics networks.

It was seen that the factor with the biggest influence is the utilization rate, where has the biggest influence in terms on percentage when it takes a value around 30%. This results led to the conclusion that it may be not worth to make big efforts from the customer company to achieve a big capacity, if this is quite expensive or requires a lot of investment to achieve. In contrast, a variety of studies of how the model performances with different capacities, can be done in order to choose the correct strategy.

It was also seen how the number of trailers obtained for the practical solution was reduced in comparison to the not FTL approach and the difference with the FTL were not as high as before. Another advantage beyond the cost of having a 30% capacity of the trailers is a lower inventory, and thus a lower inventory cost. It is important to notice that in this problem, there were not inventory cost associated to the collection centres and also no capacity problem on them, but, in case the cost of holding the inventory was a factor with a known value, the approach of FTL would have been much more expensive since the inventory on the collection points need to be much higher and thus, would offer worse results in terms of total cost than the one with the 30 % of the utilization rate, that is why more studies by taking into account inventory and different capacities should be made.

For future research, it could be calculated the total cost of inventory by establishing a value of cost of inventory holding and later the related costs associated: cycle, safety and pipeline cost for every location, it would be expected to be different the value in the factories than in the collection points, and include this cost in the model. This will lead to different results but closer to total optimization.

Another future research related to the inventory and the trailer capacity, could be to establish a replenishment inventory policy of a continuous review. For doing this, the rate of consumption of the resources from factories must be first estimated and then, taking into account the resources that are able at the factories for producing the final product and the rate of consumption, since there are many collection points that could serve the factory 1 with the resources needed (so the lead time will be short), the frequency every trailer is shipped to the factories would vary depending of the resources available at the factory and not only whenever the trailer is full, and then, once that number is obtained, the model would be more accurate for searching total optimization. Also, capacity constraints in the collection points and the factories could be added to the model case this are required.

It is remarkable to notice the importance on setting an accurate cost per load of the truck and the trailer. As it was seen, in this project two very different approaches were followed that led to different results in terms of cost. For setting the cost per loading of the different approaches, different methods were used but for a better analysis of the real performance, it is really important to establish the accurate value of cost per loading for future decisions regarding to the logistics networks, and this value should be obtained by internal methods of the company.

It is important also to notice the difference on the cost per load while the approach of a fixed value per load was taken and in the case where it was just estimated as a value of 30% of the driving hours. As it was seen, while it could work as an overall approximation in terms of average figures, it leads to inaccurate results since some orders would take a much bigger number of kilometres than others, especially those which are headed to factory 2, and while the real cost per load would be similar in both cases since it is not a big difference in the number of the animals per order, with the policy of 30 % of estimation would lead to one cost per load much more expensive than other one, and this results could influence the model in case that approach was taken.

The addition of new collection points to the existing's ones was studied. As it was seen, the best performance was achieved when an additional collection point was added, but not when two new collection points were added. This is an important strategic decision than should be taken into account due to the potential savings that could lead the construction of a new collection point. In addition, it was seen how the addition of a collection point can work as a risks mitigation in case of fuel variation, since the variation on the total cost when the additional collection point was added were less than in the model without additional ones. Due to the huge variability of the fuel price, this should be taken into account in order to minimize risks. It is worth to say that the addition of a new collection point also enhances the effect of increase the capacity, a matter that should be taken into account when determining the different performance strategies the customer company could adopt.

Furthermore, it is remarkable to mention the existence of overlapping areas regarding to the orders assignments to the different locations. It was seen how in the FTL approach, the boundaries were well defined and no overlapping areas existed, thus, the boundaries of each location are well defined almost regardless of the weight of the order,(the difference on kilometres was too small, as it could be seen on the tables), since in this approach, weight is not a determinant factor as it is on the second one, the case of not FTL, where there were not well defined boundaries and the weight of the orders played a key role where determining the assignment to the locations. It was also seen how as it was increased the utilization rate, this impact of the trailers cost diminished and thus, the boundaries were well defined again.

For the location of the additional collection points, the gravity centre method and the Weber method were used and different factors were employed. The different results when different factors were used lead to the conclusion that, when adding a new collection point, a thorough study must be done since the location decisions are very difficult and expense to reverse in the future if things does not work as expected, as they form part of the strategic decisions. In addition, regarding the fact that in this case the use of factors did not lead to any optimization of the location of the new collection point, it should be taken into account with other different methods that were not covered in this work but that may bring different solutions that could lead to total optimization.

It is important to mention again than in this model, due to the lack of information of the time of the orders, it was assumed that the orders were taken individually by the transport companies in order to be able to work under the legal frame, which states that all the orders must be collected in less than three days. In case the information of the time of the orders could be obtained in the future, it would be possible to work in new models where this issues would be taken into account, but without treat them as Vehicle routing problems (VRP), since they should be only taken into account as an analysis for the performance of the current logistics networks and for studies of new possible locations. However, with the information of the time of the incoming orders, it is possible to work in the develop of some clustering methods that take into account the different criteria could be studied in order to determine the aggregation of the orders by some cluster analysis to achieve optimization. Some criteria and constrains that could be followed may be time constrain, driver availability and distance, capacity of the truck, weight of the order, distance between orders and distance between orders and the closest collection point or farm. Later, and always thinking about future analysis where no time data is available, it could be possible to calculate a "dumping factor" based on the average number of orders that are clustered. With this factor applied and implemented in the present model, it would lead to much more realistic results in terms of performance.

In addition to what it was previously commented, another criteria for taking the orders could be the amount of resources available at the factories and collection points, and once this values are lower than a minimal value settled by the customer company, orders could be also assigned to the different transport companies. It seems clear that many variables comes into consideration of whenever the clustering of single orders in order to reduce truck cost. A scheme representing this framework is represented below:

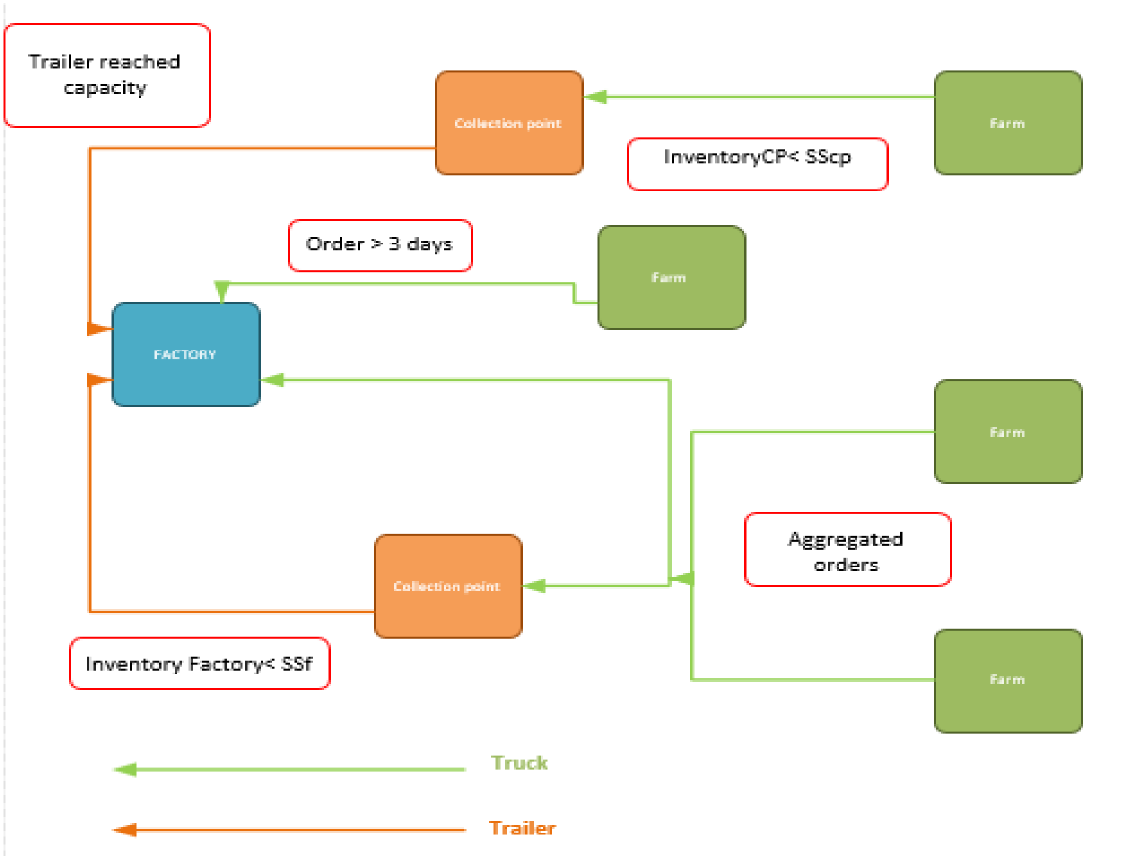


Figure 62. Possible framework of logistics network.

Where the text in the red boxes represents the conditions under the order will be send to the different locations, and, as it was said, other criteria for aggregating the orders could be added and developed for total optimization.

Regarding to the distribution of the incoming orders within the transport companies, the tool developed will lead to new distribution of the orders where every transport company will perceive the same amount of money. It is necessary to say that other considerations to the tool developed like location of the transporters, availability of the transporters, availability of the truck or the trailer, etc. could be established in the tool, so it would assign the orders to the best location taken into account all the considerations needed and it will distribute the orders taken also that considerations, but without making more differences between the transport companies.

In case the approach where the orders are not yet assigned, it could be possible to develop a model where the objective function leads to a minimization of the variance of the total cost of the transport companies. By developing this model, which can be programmed and solved with the software used in this project, a really equal distribution of that orders within the transport companies would be achieved, and that point could be used as starting point of the tool that assigns the new incoming orders instead of using the currently distribution. That would require a much smaller number of orders required to set the difference of the total cost less to the value of 1 % than it required for the current distribution of the orders.

Furthermore, this work was presented to the logistics company which has been performing this activity in Finland for several years. It was concluded that by using the data available from Finland, some dumping factors could be introduced in order to calibrate the model by representing a more realistic performance of the truck transportation. By doing this, an improvement of the results obtained by making them more realistic would be achieved. With the data obtained from the calibrated model and its simulation, the study of possible better locations of the existing collection points by relocating them using the centre of gravity method could be done. In addition, once the model calibration is achieved, it could also be used to study the implementation of new collection points that would reduce the total cost.

The policy of how the customer company clusters the orders for the truck was discussed. It should be analysed in order to set the average cost per round. A round could be defined as the number of stops at farms for a truck and then drive to either the collection point or the factory once it has done all the orders. By multiplying the average number of orders per round with the more accurate cost of loading in each farm, obtained from the data for Finland, it would be obtained the real cost per loading at the farms. In addition, the average distance covered by the truck for every round has to be calculated in order to set the optimal value of the dumping factor by comparing the results of the model with the real kilometres done.

The setting of the dumping factor could be followed by different criteria like the density of area, which is the number of orders by area, the circuity factor of that area, the average distance of one area to it collection point or facility assigned by the model with no overlapping. It was also concluded that it should be avoided taking the approach as a VRP problem, since the optimal solution would be obtained after several iterations between the VRP problem and the total optimization of the orders assignment to the locations, without having a clear starting point for making the iterations.

It should be also considered the financial aspects that the developing and implementing of this tool could arrange.

The develop of this model and the use of a simulation program , as it was seen in this work, is an important tool with a strong financial potential as it was claimed out in the results section, since the different approaches can save an important amount of money spent in the logistics networks if the optimal solution is implemented. The tool is especially useful when it comes to study different scenarios that could be divided into two main categories:

-Company currently performing activity.

In this scenario, where a lot of data is available, the use of the tool will help to study the total impact of some decisions like:

- Location of currently collection points: By looking at some KPI or other indicators, like for instance €/order on each collection point, total number of kilograms received, or other factor that the company could use, it is possible to study locally the actual performance of that location and the impact it has on the total logistics network, and in case the performance is not good, it is possible to study to relocation of that collection point ,closing or opening an additional collection point by just looking at the financial results the model will give ,and thus, help to take the decisions that can lead to save money since optimization will be achieved.

- Capacity of the trailers: It is possible also to see how the decisions of changing the capacity by modifying the number of containers, increasing or decreasing them, the impact of the cost per load, etc., will affect the performance of the logistic networks and with this, take some decisions regarding this issue.

Company planning to perform activity in another country

In this scenario, less data are available, so it is not possible to study accurately the performance of the company with the tool. However, it may help to take decisions like:

- Location of possible collection points: Based on the simulation, it is possible to see which locations would be better to place the collection points. It was seen in this work that there are many strategies to select the possible locations of the collections points, so before finally placing a collection point in some place, it is possible to run the simulation in order to see the actual performance with those locations, and in case it is not well, it can just be changed and study another location without any cost. This is a really big advantage that is important to consider since it can save an important amount of money with no required investment.

- Strategy of the truck and trailers to implement: It is possible to study which is the best strategy in order to achieve total optimization. This study could be carried out by changing the values of the capacity of both truck and trailers, the trade-off between the capacity and the cost per load, etc. All the different strategies that the company could performance, could be first simulated and later analyse the results in order to select the strategy to carry out. It is also a useful tool in case the company wants to study how the total logistics networks will react to changes in the demand, and how it will affect each location locally, and the total performance of the company globally, and if it is worth it to change the strategy in case the demand changes in order to seek for better responsiveness.

- Impact of the diverse risk factors on the performance: It is possible to analyse how the variation of some factors, like fuel price, could affect the total performance of the logistic networks, and study possible solutions that may work as risks mitigation tools for those risks.

To see the financial potential that the use of this tool could achieve, a simulation considering some strategies and scenarios described above, with some real data obtained from the company's activity in Finland, was done, and the results can be seen in Appendix 3, where, as it is shown, some important savings can be obtained depending of the strategy adopted, and thus, could help the company to make decisions regarding the different possibilities of performance based on the different trade-offs between the different strategies.

It is worth to say that this model could have some limitations due to the difference with the real performance depending of the strategy of the company. For solving this differences, the model should be changed and calibrated every time a difference is noticed with the data obtained of the real performance, by the addition of some factors that will correct the model, and once the model performance it is really similar to the current performance of the company, then it could be used to study the factors that were commented above, but it is realistic to think about implementing this tool in order to study the results and evaluate the performance of the company depending on the categories they are acting, and it is quite useful to use it also as a first approximation to how the company will performance in case no data is available or in case a change in the strategy wants to be study.

6. LIST OF REFERENCES

Ballou, R., Rahardja, H. & Sakai, N. (2002). Selected country circuity factors for road travel distance estimation. *Transportation Research Part A: Policy and Practice*, 36(9), pp.843-848.

Chen, Zixia & Yeqing Wang (2008). Research on Distribution Centers Location Problem , *International Conference on MultiMedia and Information Technology*, pp. 438 – 441.

Dantrakul, S., Likasiri, C. & Pongvuthithum, R. (2014). Applied p-median and p-center algorithms for facility location problems. *Expert Systems with Applications*, 41(8), pp.3596-3604.

Globalpetrolprices.com. (2016). Norway gasoline prices, 30-May-2016 | GlobalPetrolPrices.com. [online] Available at: http://www.globalpetrolprices.com/Norway/gasoline_prices/

Gnu.org. (2016). GLPK - GNU Project - Free Software Foundation (FSF). [online] Available at: https://www.gnu.org/software/glpk/ [Accessed 6 Jun. 2016].

Klose, A. and Drexl, A. (2005). Facility location models for distribution system design. European Journal of Operational Research, 162(1), pp.4-29.

Lackesa R.& Siepermanna M (2009). Optimal Location Planning for Self-Storage, *International Symposium on Process Systems Engineering* Pages iii-iv, 1-2166.

Reese, J. (2006). *Solution methods for the p-median problem: An annotated bibliography*. Networks, 48(3), pp.125-142.

Zi-xia C. & H. Wei.(2010). Study and Application of Center-of-Gravity on the Location Selection of Distribution Center, *International Conference on Logistics Systems and Intelligent Management*,Vol.2, pp. 981 – 984.

ACKNOWLEDGMENTS

The author of this work wants to express his deeply gratitude to Dr. Petri Helo for his humble patience with all the external problems occurred while doing this work, the help with his knowledge to the issues presented in this work the, collaboration and availability, which make possible that the present work could be finished.

APPENDIX 1: Code employed

In this appendix, the code employed for solving the model in the GLPK software is reflected. The code here described can just be copied and in the program, and it will run, but it is important to notice that the input data tables are required.

```
#==============MODEL SECTION===============
#===========declaration statements========

#----------- set and param statements------------

param n, integer, > 0; # number of clients

param m, integer, > 0; # number of facilities

param Cs , > 0; # cost of euros/km of  truck

param Cb, > 0; # cost of euros/km trailer

param Cls, >0; # cost of load for truck

param Clb, >0; # cost of load  for trailer

param Cap, integer, > 0; # capacity of trailer

param a, integer, >0; # min number of facilities opened

param b, integer, > 0; # max number of facilities opened

set I := 1..n;

set J := 1..m;

set G := 1..m;

param d{i in I, j in J};/* distance for client i to factory j*/

param w{i in I, g in G};/* weight for client i to factory j, factory1 and factory 2 0*/
```

```
param v{i in I, g in G};/*weight for client i to location  j*/

param l{j in J}; # distance from factory j to factory 1

param F{j in J}; # cost of open a factory in J

set aux dimen 2; /* for reading the data from the external file for distance*/

table nombre_tabla IN "CSV" "param__D.csv":

  aux <- [order, column], d ~ value ;

  set ax dimen 2;

table nombre IN  "CSV" "param_w1.csv":

  ax <- [order, column], w ~ weight ;

  set ab dimen 2;

  table nombre IN  "CSV" "param_w.csv":

  ab <- [order, column], v ~ weight ;

#----------- variables statements------------

var x{i in I, j in J}, binary; /* if client is assigned to facility j */

var y{j in J}, binary;/* if J factory is opened  */

#----------- objective statement------------

minimize total_cost:sum {j in J} y[j]*F[j] + sum {i in I, j in J} ((d[i,j] * x[i,j])*Cs+x[i,j]*Cls )+ sum {i
in I, j in J} ((( w[i,j]* x[i,j])/Cap)*l[j]*Cb+(( w[i,j]* x[i,j])/Cap)*Clb);   /* total cost of transport*/

#----------- constraint statements------------

s.t. client_facility {i in I}:  sum{j in J} x[i,j] = 1;/* each order  is assigned to one facility */

s.t. facility_opened:  sum{j in J}  y[j] <= b; # number of opened  facilities
```

```
s.t. facility_opened2:  sum{j in J} y[j] >= a;

s.t. constrain {i in I, j in J} :  x[i,j] <= y [j]; # for forcing open a factory if orders are assigned there

#============functional statements========

solve;

printf"\n";

printf"////////////////////////////\n";

printf" Solution for transportation cost \n";

printf " Total cost of model : %.3f euros  \n", sum {j in J} y[j]*F[j] + sum {i in I, j in J} (d[i,j] * x[i,j]*Cs+x[i,j]*Cls )+ sum {i in I, j in J} ((( w[i,j]* x[i,j])/Cap)*l[j]*Cb+((w[i,j]* x[i,j])/Cap)*Clb);

printf"Divided into: \n";

printf" Set up cost: %.3f euros  \n", sum {j in J} y[j]*F[j];

printf " Total cost of Transport %.3f euros  \n",  sum {i in I, j in J} (d[i,j] * x[i,j]*Cs+x[i,j]*Cls )+ sum {i in I, j in J} ((( w[i,j]* x[i,j])/Cap)*l[j]*Cb+((w[i,j]* x[i,j])/Cap)*Clb);

printf"Divided into: \n";

printf" TRUCK  \n";

printf" Cost of distance  truck %.3f euros  \n", sum {i in I, j in J} (d[i,j] * x[i,j]*Cs );

printf" Cost of load truck %.3f euros  \n ",  sum {i in I, j in J} (x[i,j]*Cls);

printf" TRAILER  \n";

printf" Cost of distance trailer %.3f euros  \n", sum {i in I, j in J} ((( w[i,j]* x[i,j])/Cap)*l[j]*Cb);

printf" Cost of load trailer %.3f euros  \n", sum {i in I, j in J} ((w[i,j]* x[i,j])/Cap)*Clb;

printf"\n";

printf"----------------------------\n";
```

```
printf" Number of facilities opened %s \n", sum {j in J} y[j];

printf"Where:\n";

for {j in J}

  {

 printf" Facility %s is opened: %g\n", j, y [j] ;

}

printf"----------------------------\n";

printf"----------------------------\n";

for {j in J}

  { printf" Number of Orders that facility %s is doing : %g\n",j, sum {i in I} x[i,j];

  }

printf"----------------------------\n";

printf"----------------------------\n";

for {j in J}

  { printf" Number of trailers that go from facility %s : %.2f \n",j,sum {i in I} (( w[i,j]* x[i,j])/Cap)
;

  }

  printf"----------------------------\n";

printf"----------------------------\n";

  for {j in J}

{ printf" Number of kilometers by trucks that go to facility %s : %.2f \n",j,sum {i in I} x[i,j]*d[i,j]
;
```

```
  }

  printf"----------------------------\n";

printf"----------------------------\n";

   for {j in J}

{ printf" Number of kilograms by trucks that go to facility %s : %.2f \n",j,sum {i in I} x[i,j]*v[i,j]
;

  }

  printf"----------------------------\n";

printf"----------------------------\n";

 for {j in J}

{ printf " Number of kilometers by trailers that go from facility %s  : %.2f \n",j,sum {i in I}
x[i,j]*l[j] ;

  }

  printf"----------------------------\n";

printf"----------------------------\n";

for {j in J}

{ printf " Number of kilograms by trailers that go from facility %s  : %.2f \n",j,sum {i in I}
x[i,j]*w[i,j] ;

  }

  printf"----------------------------\n";

printf"----------------------------\n";

for {j in J}

{ printf" Total Truck cost of Facility %s : %.2f \n",j,sum {i in I} ((d[i,j] * x[i,j])*Cs+x[i,j]*Cls );
```

```
  }

  printf"----------------------------\n";

printf"----------------------------\n";

for {j in J}

{ printf" Total trailer  cots of Facility %s  : %.2f  \n",j,sum {i in I} ((( w[i,j]* x[i,j])/Cap)*l[j]*Cb+((
w[i,j]* x[i,j])/Cap)*Clb);

  }

  printf"----------------------------\n";

printf"----------------------------\n";

for {j in J}

{ printf " Total transport cots of Facility %s  : %.2f  \n",j,sum {i in I} ((d[i,j] * x[i,j])*Cs+x[i,j]*Cls
)+sum {i in I} ((( w[i,j]* x[i,j])/Cap)*l[j]*Cb+(( w[i,j]* x[i,j])/Cap)*Clb);

  }

  printf"----------------------------\n";

printf"----------------------------\n";

for {j in J}

  {

 printf" Cost of load truck  %s is %g\n",j, sum {i in I} (x[i,j]*Cls);

}

printf"----------------------------\n";

printf"----------------------------\n";

for {j in J}
```

```
  {
 printf" Cost of load trailer %s is %g\n",j, sum {i in I} ((( w[i,j]* x[i,j])/Cap)*Clb);


}
printf"----------------------------\n";
printf"----------------------------\n";
for {j in J}
  {
 printf" Cost of distance truck %s is %g\n",j, sum {i in I} (d[i,j] * x[i,j])*Cs;
}
printf"----------------------------\n";
printf"----------------------------\n";
for {j in J}
{ printf" Cost of distance trailer  %s is : %.2f  \n",j,sum {i in I} ((( w[i,j]* x[i,j])/Cap)*l[j]*Cb);
  }
  printf"----------------------------\n";
printf"----------------------------\n";
#==============DATA SECTION===============
data;
param n := 1656;/* number of orders*/
param m :=6;/* number of factories*/
```

```
param Cs := 1.8979;/* cost of transport per km of   truck  in euros*/

param Cb := 1.838;/* cost of transport per km  trailer a in euros*/

param Cap := 3000;/* capacity of trailer in kg  */

param Cls := 61.227; #cost of load per truck in euros

param Clb := 89.74947918; # cost of load per trailer in euros

param a := 1;

param b := 7;

param F :=

1 0

2 0

3 5000

4 5000

5 5000

6 5000;

/*cost of open a factory in j*/

param l :=

1 0

2 0

3 579.727541

4 478.181973

5 397.7677388
```

6 487.4341561;

/*Distance from collection points to factory1*/

APPENDIX 2: Data treatment

For reading the data of the orders, in this problem different tables were created for the distance and the weight of the different approaches. There are different ways for the GLPK to read input data, so it is up to the user to choose which way fits the best for the kind of data. In this problem, .CSV archives were used, and for this kind of archives, the format required by the GLPK needs to be separated by comas. An example of how the format of the .CSV archive should be is shown in the image below for the distance value (in kilometres)

```
order,column,value
1,1,502.284679416093
1,2,1848.16732555366
1,3,151.210473895322
1,4,30.7128030756356
1,5,613.170654029917
1,6,817.426728850062
2,1,506.06685609315
2,2,1847.84713432415
2,3,154.831960254937
2,4,37.0087914344339
```

Figure 63. Format of input data for GLPK used.

For obtaining the results of the assignments of the model for a later visualization in the *My Maps* application, the following routine has to be introduced in the Command Prompt or CMD:

C:\Users\X\Desktop\gusek>glpsol -m nameofmodel.mod -o exit.txt

It is important to notice that the .mod archive that runs the model must be in the same folder than the software. The text archive with the optimal assignment for each order would be created on the same folder as well. That archive must be processed by different procedures (for example with Excel) in order to get the correct format for the visualization in the My Maps application.

APPENDIX 3: Simulation with real data

In this appendix, in an attempt to show some figures of the economic potential that could be achieved by the use of this model, a simulation with real data, provided by the company thanks to the evaluation of the performance of the activity in Finland, is going to be done for the scenario in Norway.

The changes that are required in order to evaluate the performance are the following.

Truck

As it was said in the conclusions section, for a more realistic evaluation of the performance, the cost per round was defined. It is formed by the stop at the farm (24 € /stop) and the cost of leaving container at collection point (20 €/container). In addition, the cost per kilometre has a new value of 1.42 €/km for the truck.

The average number of kilometres per round, according to data from company, is 652 km, and the average stops at farms per round, 17.

So the total cost per round of loading is about 428 €/round per truck.

Also, the average distance between farm was calculated with the data from company by calculating the average distance of farms to the closest collection point, which has a value of 78 kilometres(it is important to notice that this value varies widely depending of the area where each collection point is located) and by calculating the difference between the average kilometre per round, and the average distance of farms to collection points, just by dividing that difference between the average stops per round, it is possible to calculate an approximated number of 33.47 km of average distance between farms, which is going to be taken into.

Trailer:

Cost per loading and unloading container was established in18 €/container.

It is important to remark that the capacity of the trailers now varies between the strategies adopted depending on the number of containers the trailer is carrying: 2 or 3. Each container has 12 000 kg capacity, so the capacity of trailer varies between 24 and 36 Tons, so the cost per load also changes when capacity changes.

The cost per kilometre was settled in 1.21 €/km

In addition, it has to be taken into account that now the distance covered by the trailer has to include the return to the collection point, since the empty containers are taken back to the collection points in order to be loaded again later.

With this new numbers, the study of the performance can be done, but an important change is needed. Instead of supposing that the set of data consists on single orders, is going to be supposed that the data the company provided corresponds to the data for aggregated orders, so instead of 2 weeks orders, it could be 12 months orders, so the results would respond to an analysis for an entire year. For doing this, it is necessary to change the value of weight of the order for some random number between 8000 kg and 12 000 kg, since the average value of a round's weight is around those numbers, based on the information of the company, which commands that trucks do not leave before they have an accumulative order weight of 8000 kg and 12 000 kg is the maximum capacity of the truck, which corresponds to one container.

In this simulation, both strategies are going to be covered, the one where trailers carry 2 containers and the one where they carry 3 containers.

Results for strategy of 2 containers.

When the trailer is taking 2 containers, the cost of loading for the trailers goes up to a value of 36 €, and the capacity is 24 000 kg.

The results of the simulation are shown below:

The first results shows an important fact, collection point number 5 is not opened, according to the results of model, as it can be seen in the following figure .

```
 Number of facilities opened 5
Where:
 Facility 1 is opened: 1
 Facility 2 is opened: 1
 Facility 3 is opened: 1
 Facility 4 is opened: 1
 Facility 5 is opened: 0
 Facility 6 is opened: 1
-----------------------------
```

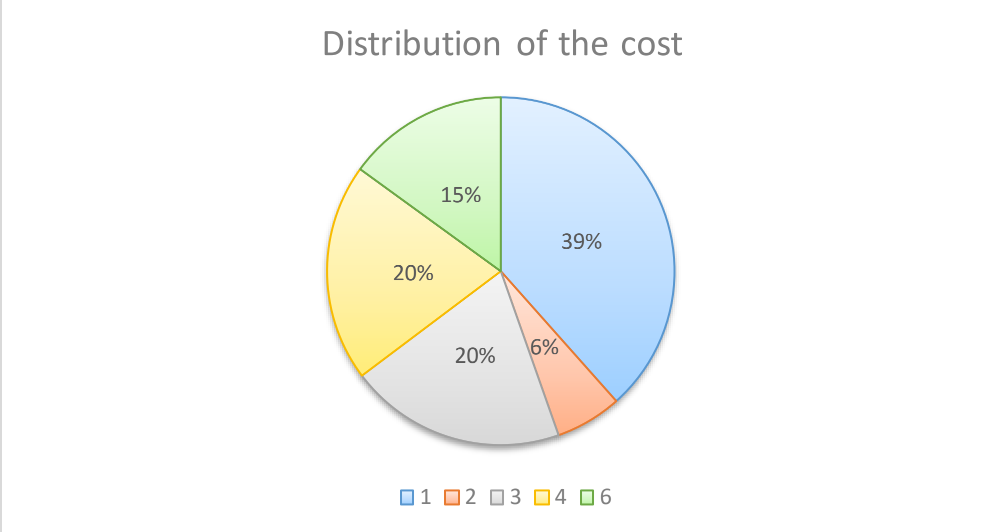
Figure 64. Results from the simulation for the 2 containers strategy

Since the set up cost is quite low, it may come to say that with 2 containers, facility number 5 is not optimal located,

Table 83. Cost by location for the 2 containers strategy

Location	Set-up	Transport			TOTAL
		Truck	Trailer	Total transport	
1	0	1365557.44	0	1365557.44	1365557.44
2	0	219561.32	0	219561.32	219561.32
3	5000	523835.92	186940.81	710776.73	715776.73
4	5000	555906.93	158532.78	714439.71	719439.71
5	0	0	0	0	0
6	5000	410707.91	117865.59	528573.5	533573.5
Total	**15000**	**3075569.52**	**463339.18**	**3538908.7**	**3553908.7**

Figure 65. Distribution of the cost by locations in terms of percentage



As it can be observed, because of the absent of the collection point number 5, the factory number 1 has a big associated cost due to the assign of the orders that, under another conditions would have been assigned to location 5.

The results of the distribution of the orders on the map are also represented

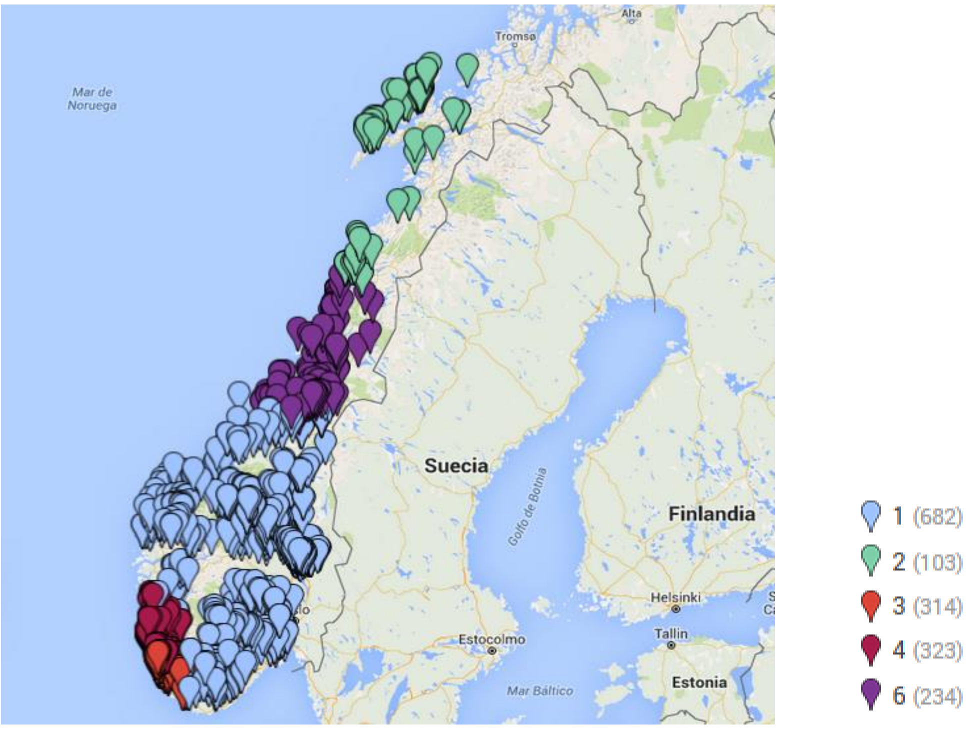


Figure 66. Distribution of the orders by location for the 2 containers strategy

By looking at the picture, is possible to see the existance of some overlaping areas, and the big number of orders that the factory 1 is doing. The overlapping areas, as it was studied in the results section, it may be an indicator that the performance is not optimized.

Table 84. Impact of the different transport cost on the total transport cost in terms of percentages

	Truck			Trailer		
Location	**Load**	**Distance**	**Total**	**Load**	**Distance**	**Total**
1	0.89%	32.77%	**33.66%**			
2	1.35%	5.36%	**6.70%**			
3	4.10%	11.89%	**15.99%**	0.14%	5.56%	**5.71%**
4	4.22%	12.75%	**16.97%**	0.15%	4.69%	**4.84%**
5	0.00%	0.00%	**0.00%**	0.00%	0.00%	**0.00%**
6	3.06%	9.48%	**12.54%**	0.11%	3.49%	**3.60%**
TOTAL	13.62%	72.24%	**85.86%**	0.40%	13.75%	**14.14%**

It is remarkable the influence of the factory 1, especially regarding to the distance cost, in the total transport cost, which represents almost the third part of it. This could lead to the conclusion that the locations can be better distributed, and that is the reason why, in this section, an attempt to relocate the collection point number 5 is going to be made.

Strategy of 3 containers

The strategy of 3 containers per trailer was also simulated. Since the capacity of the trailer has changed, the cost per load of the trailer varies accordingly and has a new value of 54 € per load, while the rest of the cost stays the same. This model does not take into account the increase that should be reflected on the cost per kilometre when the trailer is taking more kilograms because of the bigger fuel consumption, but in a more realistic model, that issue could be taken into account.

The results for the simulation shows that now, all the collection points are opened, as it is reflected in the following figure.

```
 Number of facilities opened 6
Where:
 Facility 1 is opened: 1
 Facility 2 is opened: 1
 Facility 3 is opened: 1
 Facility 4 is opened: 1
 Facility 5 is opened: 1
 Facility 6 is opened: 1
------------------------------
```

Figure 67. Results of the model for simulation for the 3 containers strategy

Table 85. Cost by location for the 3 containers strategy

		Transport			
Location	Set-up	Truck	Trailer	Total transport	TOTAL
1	0	1048101.07	0	1048101.07	1048101.07
2	0	191311.7	0	191311.7	191311.7
3	5000	638389.6	152578.96	790968.56	795968.56
4	5000	536355.47	104153.11	640508.58	645508.58
5	5000	129253	19957.74	149210.74	154210.74
6	5000	460374.39	89421.41	549795.8	554795.8
Total	**20000**	**3003785.23**	**366111.22**	**3369896.45**	**3389896.45**

The performance seems to be better optimized with the 3 strategy locations in terms on cost, and in comparison with the strategy of the 2 containers, led to the following costs reduction reflected on the table below, where it can be noticed an important reduction of the total cost.

Table 86 Results and costs reduction of the 3 containers vs 2 containers strategy

Cost	Set-up	Truck	Trailer	Total transport	TOTAL
TOTAL(€)	20000	3003785.23	366111.22	3369896.45	3389896.45
% Δ	33.333%	-2.334%	-20.984%	-4.776%	-4.615%

Regarding to the impact of each cost, it is remarkable how the distance cost of the factory 1 decreases by 8 points, but the load cost is quite remarkable.

Table 87. Impact of the different cost in the total transport cost in terms of percentage

	Truck			Trailer		
Location	**Load**	**Distance**	**Total**	**Load**	**Distance**	**Total**
1	6.87%	24.23%	**31.10%**			
2	1.17%	4.51%	**5.68%**			
3	4.81%	14.13%	**18.94%**	0.17%	4.36%	**4.53%**
4	3.96%	11.95%	**15.92%**	0.14%	2.95%	**3.09%**
5	0.91%	2.92%	**3.84%**	0.03%	0.56%	**0.59%**
6	3.30%	10.36%	**13.66%**	0.12%	2.54%	**2.65%**
TOTAL	21.03%	68.10%	**89.14%**	0.45%	10.41%	**10.86%**

The distribution on the map of the orders among the different locations is represented also in the figure below.

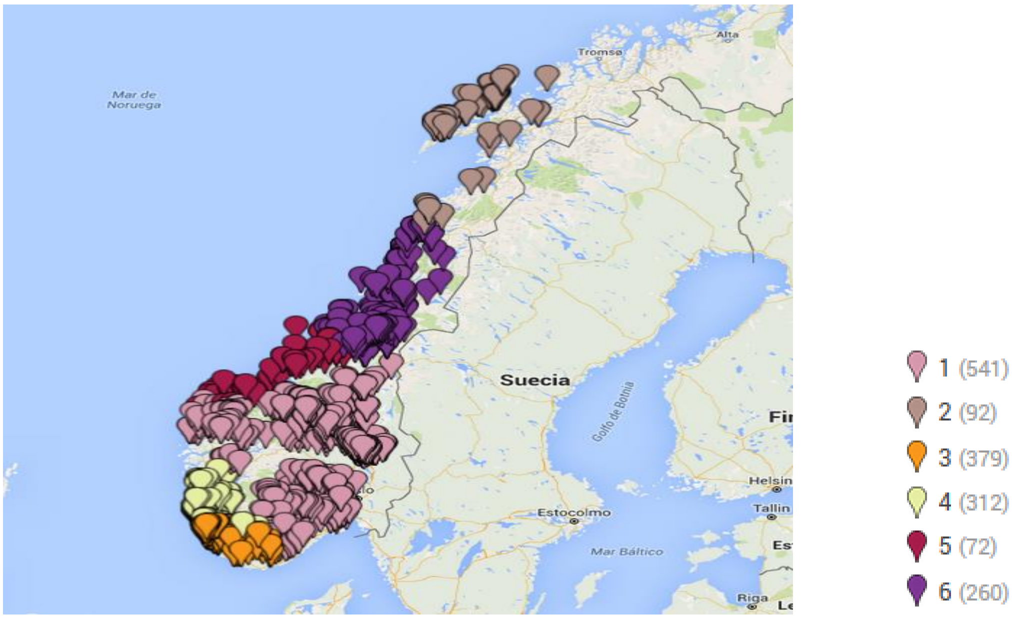


Figure 68. Distribution of the orders within locations on the 3 containers strategy

It can be seen how with a better distribution of the orders among the locations, the overlapping areas are reduced also, which confirms the prior conclusion that the 3 containers strategy is better optimized than the 2 containers one.

The indicator of the cost per order in each location, which can be used for a fast visualization of the performance, is represented below for both strategies.

Table 88.Cost per order (in €) for both strategies

	Cost per order	
Location	**2 containers**	**3 containers**
1	117.78139	113.961191
2	125.391959	122.322059
3	134.090807	123.540053
4	131.021619	121.702221
5	-	125.989167
6	134.131096	125.519412
Average	128.483374	122.17235

As it can be seen, the 3 containers strategy achieves better results that are reflected in a less cost per order in all the locations and thus in the average.

As it was seen in the results for the 2 container strategies, collection point 5 could be better placed, so a relocation of this collection point is going to be carried on. For contemplating all the possibilities, the approach of adding an additional collection point is going be made for the strategy of 3 containers in order to seek for optimization. The method followed, as it was seen in the results section, is going to be the gravity centre method since it led to the best results.

Relocation of collection point 5.

For the relocation of the collection point 5, the factor used in the center of gravity method is going to be the number of the orders. However, as it was previously said and done in the results chapter, other factors could be used in order to find the location that achieves the optimization.

The coordinates using the orders as factors are :(61.10577685,9.523976455).

When the simulation is done, all the collection points are opened now, which means that the relocation of the collection 5 achieves better results, as it was expected.

```
------------------------------
 Number of facilities opened 6
Where:
 Facility 1 is opened: 1
 Facility 2 is opened: 1
 Facility 3 is opened: 1
 Facility 4 is opened: 1
 Facility 5 is opened: 1
 Facility 6 is opened: 1
------------------------------
```

Figure 69. Results from simulation with the relocation of collection point 5**.**

In terms of cost reductions by comparing them with the previous location of collection 5, the costs reduction achieved can be observed in the following table:

Table 89 Costs reduction achieved by the relocate of collection point 5

Cost	Set-up	Truck	Trailer	Total transport	TOTAL
TOTAL(€)	20000	3046531.17	487000.304	3533531.475	3553531.475
% Δ	33.33%	-0.94%	5.11%	-0.15%	-0.01%

It can be observed that a reduction is achieved, however, it is not a big one. Probably with the use of another factor for the centre of gravity method, the results would be better in terms of cost, but just by this results, it can be concluded that is it worth it to relocate collection point 5.

Table 90. Cost by location with the relocation of collection point 5

		Transport			
Location	**Set-up**	**Truck**	**Trailer**	**Total transport**	**TOTAL**
1	0	1010924.96	0	1010924.96	1010924.96
2	0	219561.32	0	219561.32	219561.32
3	5000	523835.92	186940.81	710776.73	715776.73
4	5000	555906.93	158532.78	714439.71	719439.71
5	5000	325594.14	23661.12	349255.26	354255.26
6	5000	410707.91	117865.59	528573.5	533573.5
Total	**20000**	**3046531.18**	**487000.30**	**3533531.48**	**3553531.48**

So the final location of the collection points and factories that the company has along Norway would be the following with the relocation of collection point 5.

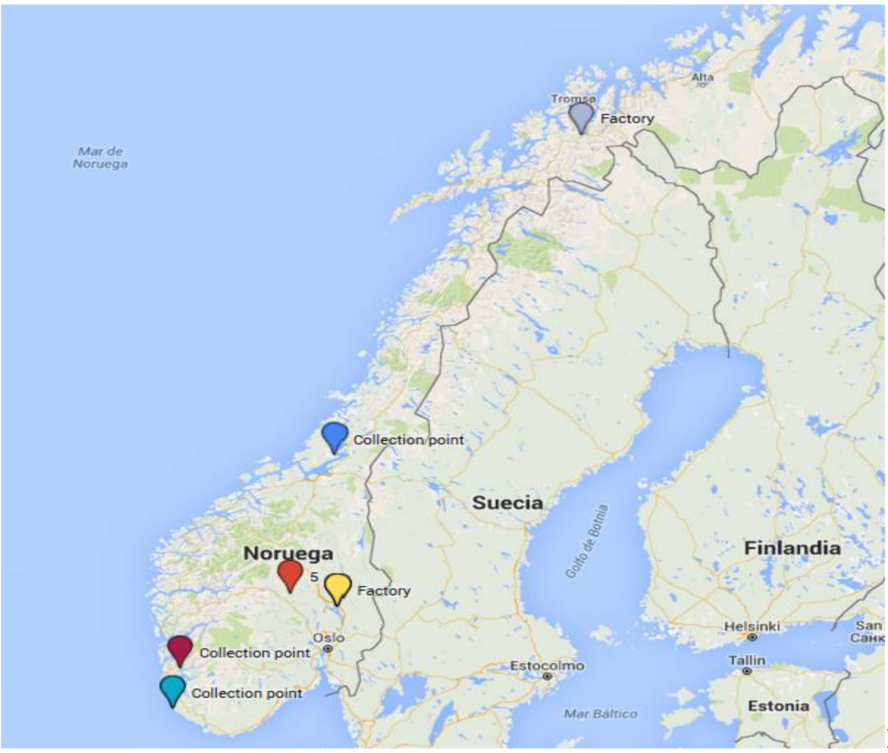


Figure 70. New location of factories and collection points with the relocation.

And the distribution of the orders with the relocation of the collection point 5 is shown below.

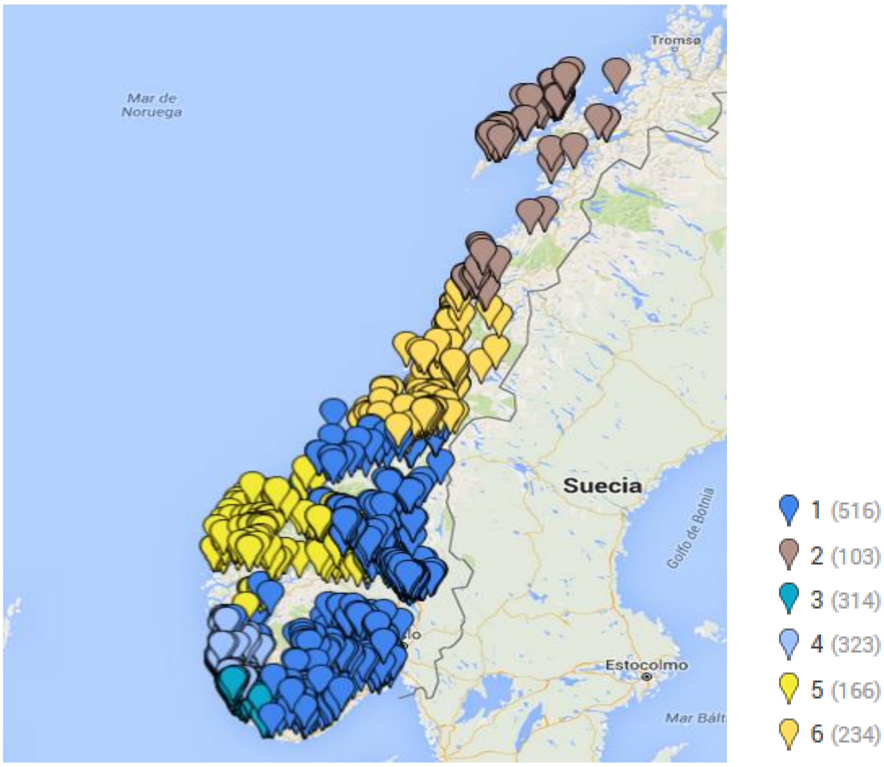


Figure 71 . Distribution of the orders when collection point 5 relocated

It is possible to notice that, while there is still an important number of overlapping areas, they are less than in the scenario with the previous location of collection point 5, so a better performance was achieved.

The cost per order, used as indicator of the performance, for the new relocation in comparison with the previous location of the collection point, can be seen in the following table.

Table 91. Cost per order of relocation and past location of collection point 5

	Cost per order	
Location	2 containers	Relocate
1	117.7813904	115.244523
2	125.3919589	125.391959
3	134.0908074	134.090807
4	131.021619	131.021619
5	-	125.533402
6	134.131096	134.131096
Average	128.4833743	127.568901

So, as it can be observed, a reduction in the cost per order in the Factory 1 and thus in the average is achieved thanks to the relocation of the collection point number 5.

Additional collection point

For the strategy of 3 containers, a performance improvement is going to be searched by adding a new collection point. The method used was again the center of gravity, and this time the factor used was cost, so the new location is (61.1283399, 9.139628272), which was achieved following the same method described in the results section.

The results of the simulation confirms that an additional collection point is worth to be opened on those coordinates.

```
 Number of facilities opened 7
Where:
 Facility 1 is opened: 1
 Facility 2 is opened: 1
 Facility 3 is opened: 1
 Facility 4 is opened: 1
 Facility 5 is opened: 1
 Facility 6 is opened: 1
 Facility 7 is opened: 1
-----------------------------
```

Figure 72. Results of the simulation for the additional collection point

The results for the costs of each location and in total can be seen below.

Table 92 Results by location for the additional collection point method.

		Transport			
Location	Set-up	Truck	Trailer	Total transport	TOTAL
1	0	719419.65	0	719419.65	719419.65
2	0	191311.7	0	191311.7	191311.7
3	5000	638389.6	152578.96	790968.56	795968.56
4	5000	521748	101566.89	623314.89	628314.89
5	5000	83534.83	13669.54	97204.37	102204.37
6	5000	460374.39	89421.41	549795.8	554795.8
7	5000	361192.18	23001.99	384194.17	389194.17
Total	**25000**	**2975970.35**	**380238.79**	**3356209.14**	**3381209.14**

In terms of costs reduction regarding the approach of 3 containers without the additional collection points, leads to the following results:

Table 93. Results in terms of costs reduction for the addition of a new collection point

Cost	Set-up	Truck	Trailer	Total transport	TOTAL
TOTAL(€)	**25000**	**2975970.35**	**380238.79**	**3356209.14**	**3381209.14**
% Δ	**25.00%**	**-0.926%**	**3.859%**	**-0.406%**	**-0.256%**

The distribution on the map, with the addition of the new collection point to the rest of the locations owned by the company, is represented.

Figure 73. Distribution of the factories and collection points with the additional one

And the distribution of the orders in the map, within the different locations available, is described in the following image.

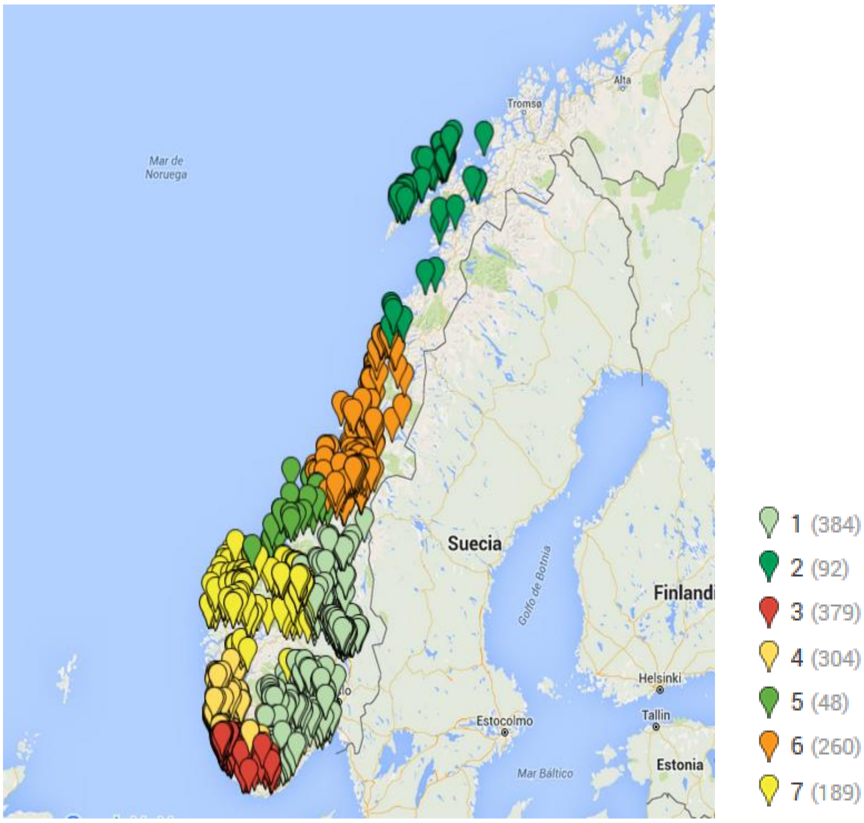


Figure 74. Distribution of the orders with the additional collection point

Finally, the cost per order indicator was also calculated. It can be observed how a reduction with the previous approach is obtained in locations 1, 4 and 5 and also in the average cost per order.

Table 94. Cost per order for the 3 containers strategy and the additional collection point added

	Cost per order	
Location	3 containers	Additional
1	113.961191	110.205216
2	122.322059	122.322059
3	123.540053	123.540053
4	121.702221	121.577959
5	125.989167	125.250453
6	125.519412	125.519412
7		121.131083
Average	122.17235	120.63294

So, as it can be inferred by looking at the results, the different strategies led to different results in terms of the cost.

If an assumption where the demand is kept constant for some years, it could be calculated the economic potential of implementing each different strategy, which could help the company manager to make the strategic and the operating decisions, which is one of the main benefits the use of this tool offers.

If a five years' time horizon is contemplated, it is possible to estimate the possible savings of selecting one of the different strategies.

First, it is possible to analyse what will be the difference whether one strategy or other one is performed in terms of containers

Table 95. Cost and savings between the different strategies

	Year				
Strategy	1	2	3	4	5
2 containers	3553908.7	7107817.4	10661726.1	14215634.8	17769543.5
3 containers	3389896.45	6779792.9	10169689.4	13559585.8	16949482.3
Savings	164012.25	328024.5	492036.75	656049	**820061.25**

As it can be observed, there is a huge difference at the end of the fifth year between using one strategy or another, more than 820 000 €. This big difference may be the fact which will make the manager to choose between one and another strategy, by looking at the potential savings. It is also possible to compare between the optimized strategies, to see if better savings are achieved.

A comparison between the performances of keeping location 5 where it is and to relocate it, in the strategy of 2 containers, can be seen below:

Table96. Cost and savings between relocate and current location for 2 the containers strategy

Strategy	Year				
2 containers	1	2	3	4	5
Current	3553908.7	7107817.4	10661726.1	14215634.8	17769543.5
Relocate	3553531.48	7107062.95	10660594.4	14214125.9	17767657.4
Savings	377.225	754.45	1131.675	1508.9	**1886.125**

The savings at the end of the year five, despite they are not remarkable, could be used as an indicator which can be interpreted as some optimization could be achieved by relocating collection point 5. Perhaps, with the use of another factor, bigger savings would be achieved, but the fact that a reduction of the cost and thus a better performance was achieved, has to be taken into account by the manager when taking the decision of relocate or not collection point 5.

Table 97 Cost and savings between current and additional collection point for the 3 container s strategy

Strategy	Year				
3 containers	1	2	3	4	5
Current	3389896.45	6779792.9	10169689.4	13559585.8	16949482.3
Additional	3381209.14	6762418.28	10143627.4	13524836.6	16906045.7
Savings	8687.31	17374.62	26061.93	34749.24	**43436.55**

Another important saving at the end of the fifth year is obtained, which may balance the decision to open an additional collection point by looking at the potential savings that can be achieved at the end of time horizon.

Next, it is possible to compare the 2 containers strategy with the current locations with the 3 containers strategy with the additional collation point, to see the difference between those two strategies which differ so much.

Table 98. Cost and savings between different strategies and approaches.

	Year				
Strategy	1	2	3	4	5
2 containers, current	3553908.7	7107817.4	10661726.1	14215634.8	17769543.5
3 containers, additional	3381209.14	6762418.28	10143627.42	13524836.56	16906045.7
Savings	172699.56	345399.12	518098.68	690798.24	**863497.8**

As it could be expected, the biggest savings difference is obtained at the end of the year five.

Finally, the following matrix reflects the savings, in terms of percentages, between the different strategies that could be followed.

Table99. Matrix of potential savings between different strategies in percentages

Strategy		*2 containers*		*3 containers*	
		Current	*Relocate*	*Current*	*Additional*
2 containers	*Current*	0.000%	0.011%	4.615%	4.859%
	Relocate	-0.011%	0.000%	4.605%	4.849%
3 containers	*Current*	-4.838%	-4.827%	0.000%	0.256%
	Additional	-5.108%	-5.096%	-5.108%	0.000%

Where, when the colour of the cell is green, it means that it is a saving respect the other strategy, and when it is red, it means that it is more expensive, while the white colour means no difference.

So, keeping this present, it is possible to see the benefits of selecting one strategy or another, and, as it was proved, the tool is useful to achieve the objective, so it can help the manager with the decision of implementing the different strategies by thinking the possible trade-offs that each one of them implies, but also by looking at the possible savings the selected strategy will achieve, which, as it was observed, could be more than 850 000 € depending of the strategy adopted.

Finally, it is noticeable to remark the importance of calibrate the model with the real results of the performance. This can be done by evaluating the activity in Finland and by carrying on the simulation also in Finland. Then, it is possible to compare the real data with the results obtained by the model, especially in terms of number of kilometres done by the truck and the trailer. If the reality differs from the numbers that are obtained with the simulation, it is possible to introduce the dumping factor, especially on the truck side, to reflect the real behaviour of the performance. Once those factors are introduced and the model results corresponds with the real results, it is possible to evaluate the differences obtained by changing the strategy as it was seen in this appendix, and, in addition, it will help to implement the strategy that is going to be finally implemented in the new country, and also to evaluate the impact of new strategies that can be accomplished.