i. Introduction

Today, distribution organizations and networks have to face the increasing complexity of achieving operational vehicle planning. Growth factors, necessary changes or simply the commitment to keep the customer satisfied are factors that make the planning process more and more difficult.

The same organizations are also obliged to adapt rapidly to their market. Distribution is evolving towards improved services, with customers expecting more and more to be delivered on time, cheaper and with a higher added value, or simply because it is a means of differentiation on a market where most of the time price is the sole discriminating factor.

Distribution expenditure is extremely high. Under pressure from the sales department, a vehicle would be sent to deliver a single order to a customer, just to keep that customer satisfied. However, it's clear that the cost structure would soon be through the roof.

An automated planning system, such as the Vehicle Routing and Scheduling (VR&S) system, is not just a cost-reducing software planner. It also ensures that a certain level of service will be maintained, no matter how much the environment changes. The system makes it possible to automatically devise vehicle routes that are still feasible for the drivers. In summary, it provides the best vehicle for servicing customers, depending on factors such as weight, volume, distance and a number of other constraints.

With VR&S tools, dispatchers will be assisted when creating and generating route plans. Their managers can rest assured that a complex distribution process will be better controlled so that the core business processes drive the distribution process and not the other way round.

While transport managers readily admit that in theory a VR&S system is an obvious tool in which they could invest, they do not immediately see all the benefits of introducing such a product in their organization.

This is because, and it is quite true, they believe that their organization, together with their business process, is unique. They have doubts as to whether a planning tool will be 100% suited to their distribution business process. They also believe that software tools are too complex to integrate into an organization and, especially, that they do not sit easily with the management of "blue collar" workers, which leads to labor relations problems with misunderstandings coming thick and fast.

The sole purpose of this document is to provide a comprehensive understanding of what a VR&S tool is, how it can be selected and what can be expected from it. It then explains some aspects of how it works. Finally, it lists some "best practice tips" for the successful implementation of VR&S tools within an organization involving distribution activities.

ii. Selection of a VR&S system

The first question that an organization is asked in the VR&S selection process is '*what are the operational expectations of the system*?' It is obvious that the primary objective of a VR&S system is to reduce operating costs. On one hand, these savings are evident and can be achieved very quickly, providing a short-term ROI. On the other hand, some savings are more difficult to determine and depend on important structural changes that can involve huge indirect costs. An evaluation must therefore be carried out to estimate whether or not the financial risk of this investment can be kept as low as possible for the purchaser.

The second question that an organization should answer concerns the functional side and deals more with how a VR&S package solves the routing problem. Depending on the complexity of this problem, it could be tempting to focus on an expensive but dedicated 100% customized solution or on the availability of a more standard approach – which is less expensive - where the complete solution could be provided but in a more standard and generic way. Evaluation of the functional spectrum of a VR&S package is important because a missing functionality can prevent effective simulation and thus deliver inaccurate planning, which leads to costly additional investment.

The third question lies at the level of integration within the organization. Integration into the existing IT structure, the existing business processes and the existing organization and systems, possibly with the question of the global acceptance of the tools, are important factors. Success depends partly on good selling of a VR&S system to an organization.

A summary will then be proposed through a list of good practice tips for implementing a VR&S system in an organization.

iii. Expectations and goals of a VR&S system

Reducing costs through effective distribution remains a priority for most organizations. Nevertheless, these projects are challenging because of the need to understand the technology and systems involved and because of the operational changes that need to take place in order to produce the greatest benefits.

Nowadays, companies still operate partially or entirely in a manual paper-based mode. By simply automating the vehicle routing and scheduling process, companies can produce distribution patterns – or routes - that are practical, more accurate (meeting delivery schedules) and cost-effective.

However, many companies feel the need not just to automate but also to optimize because of the implied expectation of reduced costs.

The automated generation of plans on the one hand and the optimization of these plans on the other, represent two different parts of a VR&S system.

Generating plans automatically

Systems that automate the creation of plans capture all-important operating characteristics of a distribution network in order to improve the planning and performance of deliveries. Systems can be deployed across an organization and/or defined centrally to leverage corporate operational benefits.
Automation reduces costs especially through the elimination of errors, the enforcement of corporate strategy and policy, the minimization of labor requirements and a reduction in the number of exceptions or incidents. It is accomplished by defining all the parameters and rules that represent the predictable aspects of a distribution model.

Optimizing plans

Optimization systems focus not only on cost reduction but also on all-important variable reductions that are representative of a distribution network. Variables such as traveling distance, working hours, regional clustering and distributed workload, are of course directly tied to a cost structure. But the best cost-effective planning does not match what a distribution organization expects. Making plans through regional clustering for instance is an important matter and is a key feature for better driver acceptance. Unfortunately, the driver's knowledge of a distribution area is very difficult to simulate through a cost variable. Another example is the weight factor. Delivering the heaviest orders first is extremely difficult to optimize in a classic cost scheme but is very easy to handle through a weight dependant variable only. Optimizing on weight reduces spare parts during maintenance operations such as band wheels??, shock absorbers, and all of the un-suspended parts of a truck.

The Traveling Salesman Problem (TSP)

Algorithm technologies that yield optimization are of course complex, but they derive from the famous TSP algorithm (Traveling Salesman Problem). The goal of this algorithm is to find the best solution to cross all of cities that the salesman has to visit, among all other possible solutions. To give an example, visiting 30 cities gives 252,859,812,191,058,636,308,480,000,000 or more than 252×10^{30} possible solutions. Another example is that visiting 70 points gives more solutions than the number of atoms estimated in the universe. This means that TSP problems evolve like a factorial function, and that even the fastest computers available need thousands of centuries to solve a 30 point problem. In conclusion, we can retain?? That when an additional point is added to a TSP of X points, more solutions have to be evaluated.

To solve the problem, optimization engineers implement heuristics. Heuristics are shortcuts that avoid evaluating all solutions and selecting only some of them to be analyzed according to some knowledge of the problems. For instance, finding the shortest way to go from one city to another is a heuristic that gives a solution with short distance coverage.

The Vehicle Routing Problem (VRP)

VRP has evolved over TSP to comply more with a distribution model than with a salesman problem. Therefore, many additional requirements have been added such as depots, vehicles,

goods, delivery points, traffic conditions, geographical information and other various constraints that can be generic or specific.

Is optimization more cost-effective than planning automation?

In small vehicle environments, the effectiveness that can be expected from an automated planning tool is similar to the effectiveness of optimization. But in a larger vehicle environment, planners cannot reasonably make thousands of possible combinations to get the best one. Therefore, optimization provides greater savings achieved by using rules of thumb in complex algorithms. In a large or complex vehicle environment, optimization is even more helpful due to numerous operational aspects that need to be automated.

In many cases, ineffective plans are not the result of a lack of optimization but rather of a lack of integration or automation of some variables of the distribution activity or network. In some extreme cases, a very complex distribution network does not provide better results due to extreme constraints. The optimization tool is therefore also unable to find possible solutions in a reasonable amount of time. The solution is either to give to the system more possibilities – in other words to reduce the operational complexity to something more "optimizable" - or to give the system more time to find a solution.

iv. Required functional aspects of a VR&S system

We have already described above that the first motivation of an automated system or tool should be to simulate as closely as possible the operational behavior of a distribution activity. Therefore, all of the characteristics and constraints of the distribution activities should be available in the tool that is provided. This implies thorough verification that requires a lot of time and effort.

It is tempting to believe that a distribution business is unique for all kinds of social, historical or business model reasons. These aspects add additional negative effects that sometimes lead to skepticism as to whether a VR&S tool could be completely suited to a distribution business model.

Fortunately, many VR&S providers have invested in the development of distribution business models. These generic models should be configurable and should cover the complete spectrum of a distribution problem. If not, the VR&S provider should demonstrate to the customer that the necessary model could be quickly derived from the existing one at no additional cost, something that is not always foreseen at the start of the project. This newly developed requirement is thus made available to the entire community and market as a standard requirement so that other customers can benefit from the same new model and the longevity of the latter can therefore be guaranteed. This also implies that the VR&S supplier needs to react quickly to the development or updates of existing models that fit partially into distribution business models.

A sort of classification of all the requirements, characteristics or constraints that the VR&S tool should take into consideration should be provided. At Routing International, we provide the following classification.

Classification of requirements and constraints

Customers' constraints and requirements are divided into three main categories:

- Functional: these are highly dependent on the business model. They need to be respected in order to guarantee seamless business model continuity without any drop in quality.
- Legal/Social: these are unavoidable in order to comply with National/European legislation, collective agreements, etc.
- Born of habit: these can be defined as *"it's always been like that"* but they have no real impact on business continuity.

All of these constraints and requirements should be modeled at different degrees. Legal/social constraints are difficult because they cannot be avoided. "Born of habit" constraints can/should normally be avoided, which gives the optimization some relaxing factors??. With regard to the functional constraints, it is important to analyze which ones reduce the quality of service or make the business model diverge from the one in the field. A delivery time window is a good example; for some companies, delivering on time is crucial, whereas other companies prefer more flexibility in their delivery option.

Entities that should be included in the VR&S model

These three categories of constraint or requirement are part of the entities that a dispatcher handles in a manual planning operation. Therefore, the model that is provided in any VR&S tool should also provide a simulation of these entities and their behaviors. There are up to five main entities: the geographical, the driver model, the vehicle model, the depot model and the goods model entity.

The geographical entity

A geographical entity is absolutely necessary in a VR&S system. This is because, given that the purpose is to create schedules and routes, we need to compute the path that vehicles are going to travel in their journeys. The path starts from a depot location and goes through all of the delivery points, which are part of the customer entity.
It goes without saying that the geographical information needs to be extremely accurate. However, it is also a requirement that all delivery points should be positioned on the map. This positioning should be provided by the tool in an automated way and should be as smart as possible to recognize addresses even if they are misspelled or incorrect.

The vehicle model entity

This is the main resource that a planner schedules, but without a driver it is absolutely useless. It should therefore be coupled to the drivers in one way or another.
The vehicle entity should be the place where the following functionalities or parameters are available:

- Capacity of the truck such as weight, volume, surface occupied, etc.
- Vehicle capacity segmentation such as compartment, trailers, containers, etc.
- Nature and aspect of transported goods (solid or liquid, mixable or not)
- Loading/unloading factors

- Start point/end points, parking points
- Filling, reloading or unloading factors (time, cost, etc.)
- Cost structure

The depot model entity

This entity may be relatively important depending on the problem. A single depot distribution scheme is of course easier to handle than a complex multiple reload depot scheme. You must therefore clearly identify what kind of depots your business requires and the purpose and parameters of the depots.

- Type of depot (parking, goods, both)
- Opening time windows
- Loading and unloading factors (time, costs, throughputs, etc.)
- Cost structure

The goods model entity

This entity concerns what needs to be delivered and where. Therefore, it concerns the information about the goods and the delivery point. Picking up goods should also be taken into account (for collecting goods) or even more difficult schemes such as delivering and picking up at the same time or at the same location.
Several quantitative aspects of the goods should also be taken into account. This is necessary if the load factor of a vehicle, the volume that it occupies, the sequence of loading or simply the time it takes to load or unload the goods in the vehicle needs to be calculated.

Another major aspect of the goods parameters are the delivery time windows. This is an important aspect of the problem since it can make things more difficult to calculate but needs to be taken into account for good quality service.
The positioning of a delivery or pick-up on the map may be another essential aspect. The system should therefore provide a process called “geocoding”. It takes the delivery or pick-up address of the goods and tries to position them on the map. The process of geocoding is extremely sensitive because if an address is incorrectly positioned, the VR&S system will calculate an incorrect path that does not accurately reflect the reality. The proposed solution will thus diverge from reality.

The main goods parameters can be summed up as follows:

- Type of distribution (pickup, delivery or both – together or in sequence)
- Distribution time windows
- Quantitative aspects such as weight, space or volume, pallets or rolls, etc.
- Address to which/from which goods should be delivered or collected
- Cost structure

v. Optional functional aspects of a VR&S system

In addition to the four main entities listed above, a typical VR&S system might also provide optional entities or modules. These might be unavoidable depending on the size and

complexity of the problem that needs to be solved. A number of them are given below, but of course the list is not exhaustive.

A driver model entity

This is the main resource that a planner schedules. But of course to plan a driver without a truck would be nonsensical. The driver is therefore associated with a truck, making him more dynamic.
The driver entity in a VR&S model should accept all kinds of features such as:

- Working time modeling
- Knowledge of distribution sectors
- Employment law constraints or limitations such as legislation relating to breaks, time off in lieu of overtime, etc.
- General or special abilities such as driving license, language knowledge
- Cost structure

A constraint solver engine

In the five entities listed above, we have described the most obvious constraints that should be modeled. But depending on the situation, there might be specific constraints that need to be simulated. A custom made solution would here probably require a development or an add-on. A standard tool, on the other hand, should propose a way of implementing any kind of constraint on any entity very quickly. Typical custom constraints include the customer's language needing to match driver's language, a vehicle that cannot deliver to certain specific places because of its size or weight, goods that cannot be mixed together in the same vehicle or part of the vehicle, etc.

A customer database

Goods that are processed every day might have a repetitive aspect due to the fact that they are always delivered to the same locations. Therefore, it might be better and easier to set some parameters related to the customer (address, load and unload factors) so that when an order has to be delivered to that customer, some of the required information is all set. This is especially typical with the address information, which does not needed to be geocoded again.

Tools for handling mapping

This kind of tool might help the user to prepare better mapping material. By providing cut, copy and paste functions, the user can build the maps on his own based on the region that he needs to cover with the tool. The tool should also provide functions for handling mapping updates without disrupting the continuation of the business.

Data import and export modules

VR&S systems are not standalone tools. They need to be part of an IT process chain sometimes made up of legacy applications and/or applications such as ERP, TMS (Transport Management System) or WMS (Warehouse Management System). These tools therefore need to be fully integrated into the IT chain in order to obtain their information and provide the routes to be completed.

vi. Integrating a VR&S system

The question of integrating VR&S into an organization is not easy. They are many tips and pitfalls that the reader needs to know about or avoid to facilitate the integration of a VR&S tool. The integration factor, which forms part of the success of a VR&S project, is made up of the following different criteria.

Collecting data

Integrating a VR&S tool into an organization is not just a question of training and configuration. It also implies the collection of all of the information needed for the planning process. This data collection procedure may require the involvement of several departments within an organization. For instance, the required information (such as information on the contractual delivery time) can start with the sales department and end with the transport department, where the dispatcher knows that deliveries to this customer might be done at a different time because the warehouse keys are available.

Gathering this information from throughout an organization might thus take the same time and effort than for any other organization software such as CRM or ERP.

Experience shows that not all information is directly available. In other words, the information is not always represented in a structured manner (such as in a table or a database on any information system already available in the organization). Indeed, some of the information can be found in the heads of major participants in the transport department, and more specifically in the heads of truck drivers and dispatchers.

IT integration

A tool like a VR&S system has no other raison d'être than to be integrated into an existing IT environment. Indeed, it needs to be interfaced with a TMS (Transport Management System), WMS (Warehouse Management System) or any legacy system installed in the organization that supports the transport or distribution information process.

Good practice will therefore mean that the IT environment should provide all of the information for the VR&S tool. If any kind of data is missing from the system, the IT environment should be adapted or modified in order to integrate the missing information. That's why a great part of the success of the IT integration will come from the flexibility of the IT environment and also the availability of IT staff to make any modifications possible.

Of course, a VR&S system as an IT tool should also have its own database. It can also be a place for integrating and storing information that needs to be used in the plan automation and optimization processes. There is however then a risk that the information will become decentralized, i.e. the information needed by the VR&S tool would come from many different databases, meaning that it would require more updates and maintenance operations to maintain integrity between the different databases.

Installation and training

If the previous step has been fully completed, the installation process can take place. Part of the installation process is the parameterization of the system. This operation can take some time but can be made easier and faster, especially if tests have been performed before, for instance in a pilot phase. In general, it is also the right moment to schedule user training, based on the parameterization already done and factual data. After the training, a remaining aspect of parameterization will take place when the first route is generated automatically, to see if the parameters converge with a real situation in which they reflect the reality.

Installing a VR&S system in a large organization where many copies of the software have to be installed on many sites (because of a multi depot situation for instance) is a very important factor that needs to be taken into account because it forces the organization to decentralize the plan creation process so that it is close to the users – the dispatchers – but on the other hand makes a lot of maintenance tasks more difficult (data backup, software upgrades, etc.).

This problem can be solved partially if the VR&S solution supports a centralized approach where both data and software can be installed on centralized computers (for instance through media such as transactional databases servers and terminal servers) but where users remain at their remote sites, close to their application field.

Training aspects in a large organization might also be more difficult to organize due to the need to gather the audience of users together in the same place at the same time with everyone's sets of data. A "train the trainer" program could be an easy solution because initial training is only given to dedicated people known as certified users, who will later train the end users – the dispatchers – themselves. In the long term, this also reinforces knowledge transfer because the VR&S solution provider and the certified users can establish preferential knowledge channels through which all of the functional and technical aspects of the VR&S system can be exchanged more easily.

Then, the certified user can disseminate the necessary information throughout the organization at its own pace.

Software maintenance can also be organized more easily because the certified users act as a conduit between the VR&S software users and the provider.

vii. Good practice tips for implementing and maintaining a VR&S project in an organization

1. Optimization goals must be measurable

Goals are the objectives that must specify what the customer wants to achieve. Thanks to optimization tools, a lot of variables can provide scalar values for comparison. By using this quantitative information, the computer can determine whether one distribution plan is better than another and the management determines if the optimization process is providing acceptable ROI. For ease of comparison, the tool should be able to import manual plans as a basis for comparison.

Another important factor is that the tool should provide different solutions. This gives the dispatchers more flexibility when choosing the best plan to put into operation. The reason for this is mainly the fact that a graphical display of a plan provides very valuable information about its feasibility, even if all of the variables are good, for the dispatchers, who then determine if a plan is feasible or not.

2. *All of the data needed for the optimization should be collected and integrated*

Data is part of the model. Unless the data is carefully collected and integrated into the system, the risk is that the plans generated will not be accurate. In organizations where acceptance of VR&S products is difficult to obtain, this will lead to suspicion about the effectiveness of the solution.

3. *The system should be integrated into an existing IT process chain and should be fully automated*

Integration is important because VR&S tools need to send their data to other automated systems, and it needs to be processed and kept in other processes of the complete IT chain. Attention should be paid to storing information centrally and not duplicating the information in several processes within the VR&S system.

Also, care should be taken to minimize manual changes, which are time consuming and prone to mistakes.

In summary, the ideal situation would be for all data to come through automated import information so that no essential data is kept in the VR&S system.

4. *The model proposed by the VR&S system should very closely represent its physical counterpart*

A model that does not fit a specific problem perfectly can sometimes be completely ineffective. It is therefore important that the model is able to support all of the features and constraints shown by a specific problem.

Simplification or shortcuts can still provide theoretically good plans but differences might be revealed when these plans are put into operation.

Removing constraints that are not absolutely necessary will sometimes provide the additional freedom to obtain more efficient plans quickly.

5. *Use the right algorithm for the right problem structure*

Due to their factorial nature, VR&S problems lead to thousands and thousands and thousands of possible solutions. The requirement for excellent algorithms is important because they have to find a solution quickly - in minutes or hours, not days or weeks.

Plans automatically generated by the algorithms need to converge quickly on a good possible solution for the problem. But a good algorithm for a specific problem structure is not the same as the algorithm for another problem structure. The algorithm should be parameterized and/or different algorithms should exist to generate different solutions required by specific problem structures.

6. *Allocate people responsible for the VR&S project and operations*

VR&S technology is "rocket science" and it is unreasonable to expect that it will work without "rocket scientists" to run it. Dedicated people should constantly check that the model, algorithms and parameterization are correctly set so that the product will meet all expectations.

In the long term, it is also unrealistic to expect that complex software such as a VR&S system will continue to provide benefits without the involvement and effort expected from the people assigned to it, and without real support from these people's managers.

7. A VR&S system is an excellent business process efficiency measurement tool

Since VR&S systems are designed for physical distribution activities, they are located at the end of a chain of successive business processes. They can therefore measure the complete chain efficiency of an organization in one go.

Systematic monitoring and control of the plans and their variables is the only way to quickly identify whether these business processes remain on track in terms of efficiency. Failure to put in place processes to monitor and improve physical distribution optimization will quickly lead to poorly utilized software.

8. Calculate an objective assessment of the ROI

VR&S system based projects are not magical cost reduction systems. Before achieving cost savings, they require significant expenditure on technology and people. A true ROI (return on investment) calculation should therefore comprise an honest assessment of the total cost of acquiring a VR&S system but also a comparison of the solutions with benchmarked alternatives.

However, it is very seldom that companies today know how effective their distribution processes are, because they have great difficulty measuring their efficiency (through a classic budget costing approach, for instance).

Establishing an ROI for evaluating a VR&S project should take into account the fact that this VR&S system is *per se* a tool that is capable of measuring the efficiency of an organization. Therefore, in complex problem structures where calculating the ROI could be very difficult, the VR&S tool is already meaningful if it is seen as a measurement tool and implies the start of systematic improvement measurement and continuous performance monitoring.