Abstract—This paper presents an overview of recent advances in the field of the vehicle routing problem (VRP), based on papers published in high-quality journals during the period from January 2015 to July 2017. A distinctive feature of the presented survey is its focus on new versions of the VRP, which have recently emerged or gained momentum, and the corresponding new solution methods, with particular emphasis on computational intelligence (CI) approaches. The list of newly proposed or currently popular VRP formulations include last mile and same day delivery, crowdshipping, bike sharing systems, post-disaster response plans, local routing in large production or cargo plants, customer-centric VRP, autonomous delivery, unnamed aerial vehicle delivery, green VRP, waste collection VRP, rich VRP, or VRP with backhauls. Simultaneously, an adequate increase of interest in the application of traditional CI methods (e.g., genetic, memetic, ant colony or particle swarm optimization, simulated annealing, or their various hybrid versions) can be observed in the VRP domain. At the same time, approaches proven efficient in other optimization areas (e.g., hyperheuristics, methods based on Monte Carlo simulations, algorithms rooted in game theory and bi-level optimizationStackelberg games,or cognitively motivated methods) have lately entered the VRP field and become a viable alternative to more traditional techniques. Since VRP is one of the fastest growing fields in the operations research area, we believe that an analysis of the recently published VRP papers from the perspective of their novelty in problem formulation and/or applied solution method can provide a true value for the CI community, especially young researchers entering the field and seeking challenges in this interesting and fast developing research area.

摘要本文根据 2015 年 1 月至 2017 年 7 月在高质量期刊上发表的论文，综述了车辆路径问题（VRP）领域的最新进展。这项调查的一个显著特点是，它侧重于最近出现或取得势头的 VRP 的新版本，以及相应的新解决方法，特别强调计算智能方法。新提出的或目前流行的 VRP 配方清单包括最后一英里和当天交付、众包、自行车共享系统、灾后响应计划、大型生产或货运工厂的本地路线、以客户为中心的 VRP、自主交付、未命名的飞行器交付、绿色 VRP、废物收集 VRP、丰富 VRP 或 VRP 背拖。同时，可以在 VRP 领域观察到对传统 CI 方法（例如，遗传、模因、蚁群或粒子群优化、模拟退火或其各种混合版本）的应用兴趣的充分增加。同时，在其他优化领域（例如，超启发式、基于蒙特卡罗模拟的方法、根植于博弈论和双层优化 stackelberg 博弈的算法或认知激励方法）中被证明有效的方法最近进入了 VRP 领域，成为更传统技术的可行替代方法。由于 VRP 是运筹学领域增长最快的领域之一，我们认为，从问题表述和/或应用解决方法的新颖性的角度分析最近发表的 VRP 论文，可以为 CI 社区提供真正的价值，尤其是年轻的研究人员进入这个领域，在这个有趣而快速发展的研究领域寻求挑战。

背拖：带回程

HE Vehicle Routing Problem (VRP), was introduced in the literature as the truck dispatching problem by Dantzig and Ramser [1] in 1959 and proven to be NP-hard by Lenstra and Kan [2] in 1981. The classical version of the VRP consists in serving a set of customers by a fleet of homogeneous vehicles with routes beginning and ending at a specified depot. The optimization goal is to minimize the cost of delivery, i.e., the total length of routes of all vehicles. In the majority of cases, a capacity limit is imposed on the vehicles, leading to the Capacitated VRP (CVRP) formulation.//容量约束

The VRP (CVRP) belongs to the most widely researched problems in the domain of

Operations Research, mainly due to its practical relevance and combinatorial complexity. The importance of the VRP stems from its direct application to everyday business routines of distribution/serviceproviding companies. Due to a huge variety of practical implementations of the problem, the VRP literature covers a broad range of possible extensions to the classical problem formulation.
车辆路径问题（VRP）是 Dantzig 和 Ramser[1]于 1959 年提出的卡车调度问题，Lenstra 和 Kan[2]于 1981 年证明是 NP-hard 问题。VRP 的经典版本包括通过一系列同质车辆为一组客户提供服务，这些车辆的路线起点和终点都在指定的车辆段。优化的目标是最小化交付成本，即所有车辆的路线总长度。在大多数情况下，对车辆施加了容量限制，从而形成了电容化 VRP（CVRP）公式。
VRP（CVRP）是运筹学领域研究最为广泛的问题之一，其主要原因是它的实用相关性和组合复杂性。VRP 的重要性源于它直接应用于分销/服务提供公司的日常业务。由于问题的各种实际实现，VRP 文献涵盖了对经典问题公式的广泛可能扩展。
On a general note, there are two main factors which determine both the intrinsic difficulty of a given VRP formulation and the potential applicability of certain solution methods. These two dimensions along which the majority of VRP variants can be grouped are static vs. dynamic and deterministic vs. stochastic formulations.

Following [3], in static problems partial vehicle routes constructed during a solution process do not change afterwards, while in dynamic formulations they may, and usually do, change (sometimes significantly) due to dynamic factors which are unknown beforehand and are only revealed later, when partial vehicle routes are already designed and frozen.

In deterministic variants of the VRP all variables are deterministic, although in the dynamic case some of them are unknown a priori. In contrast, in stochastic versions some problem parameters are stochastic (e.g. customer demands, travel times, service times or service probabilities). The easiest variants are those which are static and deterministic.

Dynamic and stochastic formulations are generally located on the other end of the difficulty spectrum.
一般而言，有两个主要因素决定了给定 VRP 公式的内在困难和某些解决方法的潜在适用性。在这两个维度上，大多数 VRP 变体可以被分组为静态与动态、确定性与随机性公式。在[3]之后，在静态问题中，在求解过程中构建的部分车辆路线不会在之后发生变化，而在动态公式中，它们可能（通常是）由于动态因素而发生变化（有时是显著的），这些动态因素在之前是未知的，只有在之后才被揭示，当部分车辆路线已经设计并冻结时。在 VRP 的确定性变量中，所有变量都是确定性的，尽管在动态情况下，其中一些变量是先验未知的。相反，在随机版本中，一些问题参数是随机的（例如，客户需求、旅行时间、服务时间或服务概率）。最简单的变体是静态的和确定性的变体。动态和随机公式通常位于困难谱的另一端。

From the application point of view, besides dynamism and stochasticity, there are several other features which differentiate the VRP formulations. The list of most popular problem aspects includes:

time windows (hard or soft),
pickups and deliveries or backhauls,
a mixed (heterogeneous) vehicle fleet,
split deliveries,
loading/capacity constraints,
multiple depots,
open routes (with no requirement to return to the depot at the end of a route [4]).
Clearly the above list refers to the most popular aspects of the VRP only, and by no means should be treated as exhaustive. A recently published book [5] provides a comprehensive description of the most popular problem variants. For a detailed VRP taxonomy the reader can refer to [6].
从应用的角度来看，除了动态性和随机性之外，还有其他几个特征可以区分 VRP 公式。最受欢迎的问题方面包括：
时间窗口（硬或软）、
取货和交货或回程、
混合（异构）车辆、
分批交货、
装载/容量限制、
多个仓库、
开放路线（不要求在路线结束时返回仓库[4]）。
显然，上述清单仅提及 VRP 最受欢迎的方面，绝不应视为详尽无遗。最近出版的一本书[5]对最流行的问题变体进行了全面的描述。关于详细的 VRP 分类，读者可以参考[6]。

The majority of the recently published VRP books or review papers can be assigned to one of the following two categories:
surveys describing major types of the VRP from a general perspective of the entire VRP field, e.g. [5] – [7];
surveys referring to particular types of the VRP, e.g. Dynamic VRP [3], Green VRP [8], Multi-attribute VRP [9], Waste Collection VRP [10], City VRP [11] or Periodic VRP [12], or considering particular aspects of the problem, e.g. the VRP taxonomy [6], [13].

最近出版的大多数 VRP 书籍或评论论文可分为以下两类：
从整个 VRP 领域的总体角度描述 VRP 主要类型的调查，例如[5] – [7]；
参考特定类型 VRP 的调查，如动态 VRP[3]、绿色 VRP[8]、多属性 VRP[9]、废物收集 VRP[10]、城市 VRP[11]或周期性 VRP[12]，或考虑问题的特定方面，如 VRP 分类法[6]、[13]。

A distinctive feature of this survey is its interest in emerging problem formulations and new CI-related solution methods. In terms of problem types the paper surveys:
new VRP formulations which have emerged only recently, e.g. last mile and same day delivery, crowdshipping, bike sharing systems, post-disaster response plans, local routing in large production or cargo plants, customer-centric VRP, autonomous delivery, or UAV delivery,
problem formulations which have been around for some time, but gained momentum over the last several years, e.g. Green VRP, Waste Collection VRP, Rich VRP or VRP with

Backhauls.
这项调查的一个显著特点是它对新出现的问题公式和新的 CI 相关解决方法感兴趣。根据问题类型，论文调查：
最近才出现的新 VRP 方法，例如最后一英里和同一天交付、众包、自行车共享系统、灾后响应计划、大型生产或货运工厂的本地路由、以客户为中心的 VRP、自主交付或无人机交付
已经存在了一段时间，但在过去几年中势头强劲的问题公式，例如绿色 VRP、废物收集 VRP、丰富 VRP 或带回程的 VRP。

With respect to solution methods the focus is on:

recently developed approaches, previously not utilized in the VRP domain, that belong to the broadly understood CI ﬁeld, e.g. methods based on Monte Carlo simulations, algorithms rooted in game theory and bi-level optimization (Stackelberg games), hyperheuristics, or cognitively motivated methods, as well as innovative applications of hybrid CI methods.

The remainder of the paper is organized as follows: the next section describes the applied methodology of paper selection and presents some statistics related to journals and papers chosen in this review. Section III discusses new, interesting problem formulations and is divided into subsections grouping particular types of the VRP. Section IV presents innovative and promising Computational Intelligence (CI) methods that have recently emerged in the ﬁeld. The last section contains conclusions.

关于解决方法，重点是：
最近开发的方法，以前未在 VRP 领域使用，属于广泛理解的领域，例如基于蒙特卡罗模拟的方法、根植于博弈论和双层优化（Stackelberg 博弈）的算法、超启发式或认知激励方法，以及混合 CI 方法的创新应用。

论文的其余部分安排如下：
下一节介绍了论文选择的应用方法，并给出了与本文所选期刊和论文相关的一些统计数据。
第三节讨论了新的，有趣的问题公式，并被分为分组特定类型的 VRP 子节。
第四节介绍了最近在该领域出现的创新和有前途的计算智能（CI）方法。
第五节最后一节包含结论。